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INFANTRY WEAPONS TEST METHODOLOGY STUDY. VOLUME V. INDIRECT FIR--ETC(U)

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CONTRACT NO DAEA 18-68-C-0004

USAIB ~~PROJECT NO~~ 3319-V

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INFANTRY WEAPONS TEST METHODOLOGY STUDY.

~~FINAL REPORT.~~

VOLUME V.

INDIRECT FIRE WEAPONS TEST METHODOLOGY.

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UNITED STATES ARMY INFANTRY BOARD
FORT BENNING, GEORGIA 31905

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1. INTRODUCTION AND SCOPE.

a. Introduction. Volume V of the Infantry Weapons Test Methodology Study summarizes the accomplishments and the findings concerning the testing of indirect fire weapons. This volume is accompanied by five appendices.

(1) Appendix I, The Indirect Fire Weapons Project Review, provides guidance and background material for the methodology study. The review, produced by US Army Infantry Board personnel, summarizes the combat tasks required of the mortar and the mortar crew. Several measures of effectiveness (MOE) are recommended for the analysis of weapon system performance.

(2) Appendix II is a project analysis outlining the major areas of interest in the design of an indirect fire weapons testing facility.

(3) Appendix III is a test and analysis plan which summarizes the findings and recommendations in this report in terms of a plan of test; the document describes the major areas of consideration and prescribes the techniques to be incorporated in testing procedures.

(4) Appendix IV is the final report of a study to develop an impact scoring system for mortar rounds. The scoring system utilizes a network of seismic sensors and measures the impact position by sensing the time of arrival at various sensor locations. The system requires a geological analysis of the impact area to determine sensor spacing and resulting scoring accuracy. A triangulation method of locating impacting rounds is also described in Appendix IV; a technical memorandum describes the improved method of using a triangulation technique to locate impacting rounds. Also included are documents containing other background material: a document describing the propagation of sound in air, which may be useful for an acoustic impact location system; and a document describing the velocity of sound in various types of soils and other solid materials.

(5) Appendix V is a Technical Data Package which describes the procedure and instrumentation for setting up an indirect fire scoring facility.

b. Scope. The methodology study was conducted by the Infantry Board to insure that service test procedures have kept pace with advances in weapon system development and capability, training procedures, doctrine changes and developments. (The study directive, which describes the goals of the program in detail, appears in Appendix I of Volume I of this report.) This document is the fifth in a series which deals with various types of Infantry weapon systems. The five volumes of this report are:

Volume I - Small Arms Weapon Systems

Volume II - Antitank Weapon Systems

Volume III - Light Machine Guns

Volume IV - Grenade Launchers

Volume V - Indirect Fire Weapon Systems

The study was guided by four basic objectives. These objectives were applied to each category of weapon systems described above. The four basic objectives are paraphrased below:

(1) Determine those factors influencing the evaluation of Infantry weapons in a realistic combat environment.

(2) Develop techniques and methods to measure the impact of critical factors influencing weapon system performance.

(3) Isolate those factors which are subjective, involving judgement and experience, and which are not amenable to measurement, and establish the relative importance of each.

(4) Develop automated test facilities which will permit operational testing with a minimum of maintenance and support.

In accordance with contract modifications, the only Infantry weapon system for which test facilities were constructed (objective 4) was the rifle system. The Infantry Board does have limited capabilities with respect to other weapon systems, but fully automated test facilities have not been developed.

Treatment of these four objectives required consideration of specific factors. First and foremost, as identified by the Indirect Fire Project Review, indirect fire weapon system evaluation must be oriented toward the combat tasks and combat actions required of the system when employed on the battlefield. The next major effort was to develop appropriate measures of effectiveness to quantify performance to form the basis for decision making.

The primary measure of effectiveness used for other weapon systems is a mission accomplishment measure based on the number of targets destroyed by competing weapon systems. Due to the characteristics of the mortar system, an area fire weapon as opposed to a point fire weapon, an overall mission accomplishment measure is difficult to conceptualize. Consequently, new measures were required. In addition to the existing accuracy measures, supplementary measures of weapon system efficiency were developed to provide a more complete picture of system performance. Factors which could not be accounted for by measures of effectiveness were identified; these factors must be treated subjectively. As a result of this analysis, an experimental design was developed which takes into account the critical factors; an analytical procedure was established to provide the basis for final decision inputs. Further, test facilities were designed which take into account as many factors as possible by duplicating the types of targets against which indirect fire weapons are normally employed. An indirect fire test facility was not constructed due to a change in the methodology program. The preparation of Volume IV, Grenade Launcher Test Methodology, was substituted for the task of constructing a test facility for indirect fire weapons.

2. BACKGROUND.

a. Purpose of the Report. The purpose of this report is to summarize efforts and findings concerning indirect fire test methodology. This methodology study was conducted by the Infantry Board to insure that service test procedures incorporate state-of-the-art test and analysis techniques. The study is supported by the Mellonics Division of Litton Industries, Inc., Sunnyvale, California. The services were provided under the terms of Contract Number DAEA 18-68-C-0004.

~~b. Chronology.~~ Since the first 4 years of the methodology study were oriented toward small arms, relatively little effort was focused on indirect fire weapons during that period. In 1969, an effort was begun to develop an improved scoring system for determining the accuracy of indirect fire weapons.

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The effort was undertaken via a subcontract with the Geophysics Laboratory of the University of Michigan. The final report appears in Appendix IV. Also, in 1969, a project analysis was completed and published. These events and other related tasks that have been accomplished are summarized below.

April 1969 - Seismological Study of Nolan Range

September 1969 - Project Analysis - Indirect Fire Test Facility

June 1970 - Evaluation of Closed Circuit Night Television

June 1970 - Acquisition of ADPE

August 1971 - Technical Memorandum - An Improved Method of Triangulation to Determine Point of Impact

3. EXECUTIVE SUMMARY.

a. Technical Approach. A weapon system alone is a meaningless entity since its effectiveness is dependent on where it operates, against whom, and how it is employed. In fact, the factors that can influence weapon system performance number in scores and the combinations of factors number in the hundreds.

The ultimate weapon test occurs in combat but the combat environment does not lend itself to testing. The measures of effectiveness are valid: number of enemy casualties, number of friendly casualties, and time to accomplish mission. But even in combat, cause and effect relationships are difficult to determine. Mission success or failure is dependent on too many factors to permit the establishment of causal relationships without adequate control. Further, data collection to establish an objective decision basis is extremely difficult and often costly to acquire. Lastly, the risk of loss where dependence is placed on an untested item may be high. Although the ultimate test of weapon or equipment effectiveness may occur in combat, combat is not the place where testing should occur. The solution to the problem of improved testing is in the development of the combat testing techniques.

As indicated by the chronology of events, the primary effort during the first 2 years of the contract was oriented toward an improved method of measuring indirect fire weapon system accuracy. More recent work during the final months of the contract, as described in paragraph 4, has indicated that an automated system of determining point of impact is less important than originally envisioned. There is a need to focus more precisely on the crew drill actions since mortar responsiveness is directly dependent on the ability of the crew to prepare the weapon for action. Further, the crew must be able to keep the weapon operating efficiently as fire commands are issued. Problems of stability, such as base plate slippage, must be examined thoroughly. Related to stability is reliability which is also examined during the mortar performance evaluation. Finally, the weapon system must be mobile and a measurement of this aspect of performance must be accomplished. Consequently, five categories of measures were examined and are discussed in the following section. These are:

Accuracy

Responsiveness

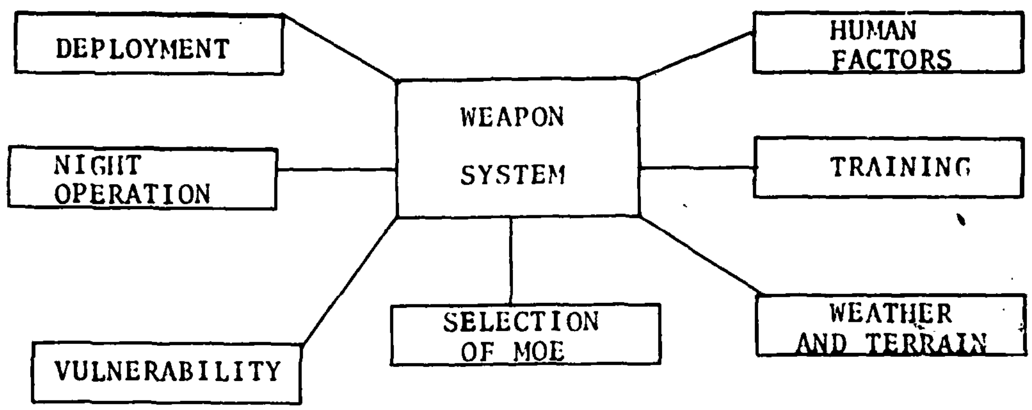
Stability

Reliability

Mobility

Each of these categories must be examined while the weapon system is engaged in simulated combat operations. The crews must perform the combat tasks and actions required of the weapon system under conditions normally associated with combat. Time pressure, limited visibility, unprepared terrain, and crew shortages are some of the test conditions under which evaluation of performance must take place.

This analysis discusses the major factors that should be considered in operational testing of mortar systems and offers the rationale for and means of incorporating these factors. The factors discussed appear in Figure 1.



FRAME OF REFERENCE FOR THE OPERATIONAL
TESTING OF MORTAR SYSTEMS

Figure 1

The methodology study has identified these essential elements of analysis:

(1) What are the measures or data showing performance, in terms of the five categories identified above, of mortar systems in various combat situations?

(2) What are the actual accuracies of candidate weapon systems with strict control placed on the FDC and FO functions and with such operational problems as uneven terrain and limited visibility?

(3) What is the rectangle of dispersion under various operational test conditions?

(4) Can the ammunition component of the weapon system be adequately examined in terms of fuzing, preparation, stowage, etc?

(5) What is the responsiveness of the weapon system and how can it be measured?

(6) What measures can adequately quantify mobility, reliability, and stability?

(7) Can the vulnerability of candidate weapons be adequately compared?

Section 4 of this report discusses operational questions of this type; methods and techniques for answering these questions are presented.

b. Manpower Expenditures. The amount of contract labor expended during this portion of the methodology study is shown below.

Operational Analysis	5 man-months
Statistical	3 man-months
Engineering	3 man-months
Technical	4 man-months

In addition a subcontract (see contract and report in Appendix IV) was let to the Geophysical Laboratory of the University of Michigan to explore the possibility of using a seismological system to score impacting rounds. The results of the study, discussed under Objective 4 in the following section, describe the findings of the indirect fire portion of the Methodology Study in terms of the support contract objectives.

4. TECHNICAL OBJECTIVES. The purpose of this analysis is to establish basic test concepts for the operational evaluation of mortar systems. The concepts include the development of test facilities, test methods and procedures, instrumentation requirements, and data collection and processing requirements. To provide general guidelines for this study, an attempt is made to identify critical factors which should be considered as the methodology study continues. Each critical factor is discussed and recommendations for elimination or incorporation are made. If the factor is defined to be within the area of responsibility of the expanded service test, or is expected to have significant impact on weapon system evaluation, procedures for incorporation are presented. In this manner, this project analysis systematically narrows the number of factors until the scope of the mortar methodology study is defined.

The goal of the mortar methodology study is to insure that critical factors are included in expanded service testing so that the assumption can be made that the results from an expanded service test are the same results that would be achieved if the weapons were tested in combat. The analysis is presented in terms of the four basic objectives of the methodology study. The efforts and findings in pursuing the study objectives are described below.

a. Technical Objective 1.

(1) Introduction. The first technical objective of the Infantry Weapons Methodology Study is stated below.

> Determine those factors influencing the evaluation of indirect fire weapon systems in a realistic combat environment.

The determination of factors influencing the performance of mortar systems in a realistic combat environment is discussed in the methodology review (Appendix I) and the project analysis (Appendix II). This section specifically addresses the major factors influencing operational testing. No field experiment was performed to test scientifically the assumptions outlined herein. However, field experimentation oriented to the operational testing of other weapon systems and previous work in the mortar systems area at other agencies testify that the following factors are indeed important in mortar system evaluations:

(a) Deployment

(b) Selection of Measures of Effectiveness

(c) Human Factors

(d) Terrain

(e) Training

(f) Night Operations

(g) Vulnerability

(2) Deployment. The employment of mortar systems varies with the tactical situation. There are certain overriding principles which govern the successful use of organic and attached mortar systems for small units (squad, platoon, company). The mortar systems unit should strive to:

(a) Support the company as a whole in a general support role and not any particular subdivision of the unit. Fires should be rapidly massed and shifted to support the entire company in this role.

(b) Support rifle platoons in a direct support role. Capability to mass fire on targets by mortar units or sections for direct support to rifle platoons is limited.

(c) Support rifle platoons in an attached role.

(d) Displace mortar sections in echelons to avoid loss of close supporting fires during displacement. The method of displacement depends upon the tactical situation, whether heavy fire support is required early or late during the attack, whether the attack period is anticipated to be long, and whether the distances involved are long. Temporary positions should be near the main route of advance to facilitate rapid displacement to the next location.

(e) Make night attacks short and violent. Probable effects of preparation for a surprise attack must be weighed against possible surprise effects.

(f) Isolate zone of attack at night. Protect supported unit upon its arrival at the objective.

(g) Establish mortar section firing positions far enough forward prior to night attack to prevent need for displacement during attack or after objective recurred.

(h) Provide continuous fire support during exploitation and pursuit by displacing one mortar at a time and leap-frogging the remaining mortars.

(i) Supply ammunition by Army aircraft or other accelerated means during exploitation and pursuit.

(j) Plan on engaging fleeting targets of opportunity during exploitation and pursuit.

(k) Employ mortars for movement in the same manner as exploitation and pursuit, except for slower displacements. Security missions may be supported by attacked mortar sections without an FDC.

(l) Plan area defense support fires forward of defense position to limit enemy penetration and to the rear to support counterattack.

(m) Locate the mortar section farther to the rear for mobile defense to prevent its being overrun if the rifle company being supported is in the fighting force.

(n) Plan fires primarily for the killing zone if supported rifle company is part of the striking force. Plan some fires to aid the striking force in its movement to the killing zone.

(o) Aid frontline companies in breaking contact and movement to the rear if the supported rifle company is acting as the battalion covering force during a daylight withdrawal.

(p) Accompany night reconnaissance party in addition to supporting detachments left in contact to give appearance of normal fire support and to aid the detachment in its night withdrawal.

(q) Locate maximum fire power well forward to take the enemy under fire for early deployment during delaying actions.

(r) Prepare for rapid and frequent displacements to the rear during delaying actions.

(s) Launch any necessary counterattack to disengage forces decisively engaged during delayed actions.

(t) Use air observers to determine firing data during delaying operations.

(u) Plan fires on assembly areas in the vicinity of likely crossing sites during a river line defensive.

(v) Use camouflage nets during desert operations and park vehicles at other than the firing position.

(w) Exercise care of proximity fuzes and metal parts during wet weather operations.

In fulfilling these roles, the crew must accomplish some 27 basic combat actions which are shown in the Project Review, Annex E of Appendix I. During the Project Review these 27 actions were analyzed in terms of crew tasks. It was determined that four specific actions contained representative tasks and were in essence equivalent to the entire spectrum of 27 actions. These final four actions were:

Defense

Retrograde Operations

Attack

Advance to Contact

Each of the above actions can be examined using the crew task cycle:

Pre-mission tasks

Mission tasks

Post-mission tasks

Transportation tasks

In turn each of the task/actions must be examined in terms of the categories of measures of effectiveness (MOE) so that appropriate MOE can be identified for each task/action.

(3) Selection of Measures of Effectiveness. The next step was to select or develop measures of effectiveness (MOE) and test techniques which will provide information on the weapon system's capability to perform the basic combat tasks. These MOE and techniques are described under Objective 2.

The missions and the tasks were compared directly as shown below:

COMBAT ACTIONS / TASKS	Defense	Retrograde Action	Attack	Advance to Contact
Pre-mission				
Fire-mission				
Post-mission				
Transportation				

Analysis of these combinations appears below.

(a) Pre-mission Tasks. Analysis of the pre-mission tasks required while performing the combat actions yields the following crew tasks:

Unsecure base plate

Unsecure tube

Off-load base plate

Off-load tube

Unpack ancillary equipment

Unsecure ammunition

Off-load ammunition

Position base plate

Attach tube

Attach ancillary equipment

Position aiming stakes

Lay weapon

Secure positions

Camouflage and conceal

Prepare ammunition

Seat base plate

Only the tasks of position security and camouflage and concealment differ to any degree in the pre-mission activity of preparing for the four basic combat actions. Assuming that position security and camouflage and concealment would be identical tasks for competing weapon systems, these tasks can be eliminated from the set of pre-mission subtasks. Examining the five categories of MOE (accuracy, responsiveness, stability, mobility, and reliability) only responsiveness is associated with the pre-mission task of preparing to fire. Several individual tasks are measured and then folded into a single overall responsiveness MOE, time to first round. For simplification, the primary measure should consist of the overall time it takes to place the weapon into action. The time begins with the operations order which is given while the weapon is in the transport mode and terminates with the initial round of the fire mission. This measure incorporates all of the individual times for the pre-mission activities described above.

(b) Fire-mission Tasks. Regardless of the tactical combat action, the individual crew actions in firing the weapon, adjusting, firing for effect, and preparation of ammunition are identical. Of the five categories of MOE, accuracy, responsiveness, stability, and reliability are all intimately associated with the five mission tasks.

(1) Accuracy. Two basic measures are needed to describe weapon system accuracy; rectangle of dispersion and offset error. The rectangle of dispersion is a measure of the stability and accuracy of the system while firing for effect. A small rectangle indicates a stable platform. Offset error is a measure of weapon/crew performance. Ideally, the offset error should be less than the rectangle of dispersion. These data are related to soil type, topography of terrain, and number of rounds fired.

(2) Responsiveness. With the fire direction commands carefully controlled, that is, each subsequent fire command given as soon as the previous round is fired, the responsiveness measure becomes the time to complete the fire mission. The measure begins with the fire command and ends with the final round in the fire for effect action.

(3) Stability. The problem of base plate shifting on varying soil types or terrain slope can require extra actions on the part of the crew and consequently increase the time to FFE and decrease the accuracy of the system. The number of adjustments made to control mechanisms in order to maintain tube alignment should be carefully noted. This is the primary measure to be used in conjunction with the responsiveness and accuracy measures discussed above.

(4) Reliability. Failure of specific weapon components is a measure of system reliability. A record of each round fired throughout the service test should be kept as well as a record of each malfunction. The MOE recommended is number of rounds between failures.

(c) Post-mission Tasks. The crew tasks during this portion of the crew task cycle are essentially the reverse of the pre-mission tasks. Responsiveness in preparing the weapon system for movement is the key variable or set of measures. Data on each subtask are collected and folded into a single post-mission measure, time to prepare for movement. The time is measured from the last round fired (or the time when the action order is given) until the system begins movement to another location. Examples of individual subtasks are shown below:

Pack ammunition

Load ammunition

Secure ammunition

Disassemble weapon

Pack ancillary equipment

Load tube

Load base plate

Secure tube

Secure base plate

(d) Transportation Tasks. The final portion of the crew task cycle focuses on the task of transporting the weapon system. To have maximum effectiveness to comply with fire requests on fast moving battlefields the weapon system must be able to accomplish rapid and frequent displacements. Therefore, transportability becomes an extremely important factor. Areas that should be examined include capability of the carrier (i.e., is the carrier suitable and adequate for the weapon system) and compatibility of the carrier. In most mortar tests the carrier will be identical for both candidate systems. Unless system weight varies considerably, vehicle speed and cross-country speed will not be affected. Therefore, the test must focus on compatibility with the carrier vehicle or with carrying personnel if the weapon is hand carried.

(1) Vehicle Carried Mortars. Evaluation of weapon/crew/ammunition/vehicle compatibility is subjective and is discussed under Objective 3.

(2) Lightweight Mortars. Mortars which can be carried by the crew should be evaluated for the transportability using the facilities. The measure is various times to cross obstacles and movement times.

(e) Summary. Examination of the relationship between the four stages of the crew task cycle and the four primary combat actions show that each of the combat actions requires the crew members to perform identical sets of tasks. Consequently, the use of a single combat action is recommended: retrograde action. This action requires the crew to displace, set up, fire and displace. These are the crew tasks common to all combat actions.

The MOE described above under each task cycle are the MOE recommended for use in the methodology study. Test procedures and techniques for using these MOE are described under Objective 2.

(4) Human Factors. Human factors considerations pertinent to the conduct of weapon systems testing fall into several broad categories which will be discussed below. These are the man-machine relationship problem, crew proficiency, the imposition of combat stress, and motivation. Generally, these factors are not as subject to rigid experimental control as are other aspects of test procedures, so it is necessary to design means of minimizing any bias that could result in test data from the impact of these variables.

To achieve maximum effectiveness with any weapon system, the crew must work as a unit with complete cooperation, and the hardware must be designed to interface with the crew without undue restrictions. Measures should be used to quantify these aspects of performance. These compatibility characteristics are most easily measured using responsiveness MOE. Consequently, responsiveness is the primary area of consideration for indirect fire weapons and accuracy the secondary area of consideration. Responsiveness is a measure of the ease with which the task of putting the weapon into action is accomplished, and can be quantified with such measures as time-to-first-round and time-to-fire-for-effect. Accuracy is a measure of the ability of the weapon system to respond to fire commands with proper orientation of the weapon system and proper adjustments to the aiming mechanism. Accuracy is measured by the location of the impacting rounds.

Variability among individuals and design differences between weapons dictate that weapons be compared using mean performance from sets of crews. Statistical considerations dictate that care should be used in selecting test soldiers for participation in operational service testing. The objective of the service test is to predict mortar system performance levels that can be expected under combat conditions. The goal of the service test is to select the most effective mortar system for use in the combat environment. Generalization of results from the test situation to the combat situation is a necessary step and the validity of this generalization is directly dependent on the fact that factors influencing the combat performance of a weapon system must be present during the service test. One of the most important factors is a representative sample of test soldiers. The use of soldiers that are atypical or the use of technical representatives during the measurement of performance under test conditions will not permit generalization of results to the combat environment. Further, the use of sample sizes that are too small will result in the inability to reach statistically conclusive results. Sample size considerations are discussed in detail under Objective 2.

Once a representative sample has been selected from the parent population a second human characteristic must be considered. The test soldier must be adequately motivated to produce a level of performance that could normally be expected under combat conditions. The introduction of combat realism into a test environment is recognized as a major problem to which no completely satisfactory solution has been found. Simply stated, no adequate method has been devised to present the test subject with a credible threat to his life in a simulated combat situation wherein only the subject's side employs live fire. Hence, the basic motivations of individual and unit survival may be largely absent and must be replaced by alternatives. One of these alternatives is stress. Generally, stress can be introduced by requiring the subject to conduct monotonous and repetitive tasks in the presence of constant distractions, by requiring the performance of complex tasks under severe time constraints, by requiring decisions in the presence of excessive and often irrevelant infornation inputs (information overload), and by sleep deprivation and physical fatigue. However, most of the above substitutes have a derogatory effect on motivation, a factor of prime concern in combat and during weapon testing. Consequently, stress-inducing techniques have dubious value in the expanded service test. The trade off between the added realism provided by stress-induced subjects and the possible reduction in motivation should be studied further before stress from fear is simulated by stress from other sources in the expanded service test. Instead of duplicating the extreme and/or erratic responses, substitute stress will likely reduce motivation from a near maximum for each individual's need-achievement level to some lower level. The aim is to duplicate combat performance; the result of induced stress will likely move the individual away from that aim. Until this relationship is more thoroughly understood, all types of induced stress should be de-emphasized except time constraints.

Motivation can be enhanced by making the test situation as near to combat as possible. The test subject should perform actions similar to those performed by the combat soldier. Time pressure to dismount, set up, and fire should always be present. Distractions such as adjacent firers, artillery, and small arms simulators would assist in adding realism. The test soldier should be combat equipped and the test should include preliminaries such as a briefing prior to an action. The fact that performance will be measured and compared to other individuals or groups should be related to the test soldier. Lastly, the direct effects of the crew's efforts should be fed back to the crew through the FO, FDC or the system being used to simulate these functions.

Another human factors problem alluded to in the description of the crew task cycle in the previous section is the possibility that some physical characteristics such as size may be an asset to a mortar crew. Normally, test soldiers are selected for expanded service tests using an acceptable sampling procedure that insures that they are not atypical representatives of the present population. Selection techniques are discussed in detail in Volume I of the Study. Uniformity in proficiency is also enhanced by training procedures. Test personnel are selected on the basis of being close to the norm for the particular specialty area. The result of training and selection procedures is that the individual selected has a reasonably representative proficiency level normally expected of combat troops. Selection should always be based on MOS, experience in MOS, proficiency, and duration of combat experience.

Even with all of the above safeguards, occasionally some characteristic of human component of the weapon system, when varied, will have a significant impact on system performance, especially in the comparative testing of such complex weapon systems as the mortar system in which minor differences in operator proficiency can account for major differences in performance. Crew performance should be analyzed with respect to physical characteristics to determine if a possible interaction exists between weapon system performance and some human factor. The existence of an interaction between independent variables and perhaps some physical characteristic may be an important aspect of the man/weapon interface. Care must be taken to insure collection and incorporation of much personal history data as possible into the analysis of performance data so that interaction effects, if present, can be found. Particular attention should be paid to such parameters as prior experience. This analysis may be useful in explaining anomalies in the data and for improving weapon system performance.

Another human factor related to crew performance is attrition of crew members. The impact of the loss of a crew member should be evaluated during the expanded service test. Frequently, units and crews do not have a full complement of personnel and must operate under handicaps. Factors such as base plate weight, transportability, and ammunition preparation can be seriously affected by shortages in personnel. Weapon systems that operate efficiently with smaller crews or under reduced strength conditions have very desirable characteristics from an operational point of view.

Methods and techniques for consideration of these factors are discussed under Objective 2.

(5) Training. In testing new weapons side-by-side with existing systems a risk occurs in that lack of familiarity of the crew with the new weapon can produce a bias in favor of the existing weapon system. Crew effectiveness depends heavily on the ability of a group of men to perform together in a smooth and efficient manner. A crew works as a team and, consequently, has a common set of objectives. To accomplish the objectives a crew must off-load and position the weapon platform and tube accounting for any idiosyncrasies, prepare the platform for recoil absorption, lay the weapon, and prepare the ammunition. Thus, the effectiveness of a crew-served weapon is dependent on how well each of these tasks is performed.

The training procedures for crew-served weapons need close examination before crews are trained for participation in operational service testing. The normal procedure for preparing crews for service tests follows this pattern:

(a) Previously trained mortar crews are selected and trained in the new weapon system.

(b) When a new mortar system is to be tested, the FM for the most similar weapon system, in this case the 81-mm or 4.2-inch mortar system, is consulted and a training schedule prepared.

(c) When existing training procedures state that dry fire practice requires 2 hours and gun aiming practice requires 4 hours, the new training schedule usually states the same thing even though the weapon configuration may be quite different.

Each new weapon system should be evaluated for its unique needs, and training procedures to optimize crew performance should be developed with this goal in mind. Side-by-side tests using two different training procedures may be necessary to determine optimum training techniques. This effort will not only insure better trained crews for operational service tests, but will permit the introduction of new, more effective training techniques along with the issue of the weapon. The training gap that sometimes occurs with the introduction of new weapons will be eliminated; combat crews will not be trained on new weapons with old weapon training methods for that period of time that it takes to realize that problems exist plus the time it takes to implement improved training procedures.

Another function of training is to reduce the number of test cells in the expanded service test design. For instance, a mortar is normally layed or oriented by using a compass, an aiming circle, or by using an adjacent mortar. Normally, one of these methods is used most often in combat, the most expedient method. To test all three of these methods under rigid test conditions would require increased sample sizes, more test crews, and more time. The training period can be used to determine the most suitable method of using a weapon system when more than one method exists. This method is then incorporated into the service test although crews continue to train using alternate methods from time to time. The training period provides an opportunity to examine alternate methods without expansion of the test design.

Selection of appropriate MOE is discussed under Objective 2.

(6) Terrain. Terrain influences mortar systems in a different manner than it influences direct fire systems. In the case of the latter, terrain influences range estimation, target exposure times and target speeds. In the case of the mortar, terrain influences such factors as weapon stability, base plate seating characteristics, and weapon set up time. The service test should allow for the influences of terrain by scheduling live fire missions from sloping terrain and from terrain of different soil consistencies (e.g. sand, clay, mud). Time pressure should be imposed while the crew sets up the weapon system, settles the base plate, registers, and so on, until fire for effect (FFE) is achieved as a function of varying terrain.

Other aspects of terrain, such as target acquisition, are neutralized by controlling the functions of the forward observer and FDC.

(7) Night Operations. With the development of night vision devices and improved artificial illumination techniques, night combat operations are becoming increasingly important. Consequently, operational testing should include an evaluation of the compatibility of a new weapon system and the night combat environment.

Mortar systems equipped with or operated in conjunction with low-light level vision aids, such as passive night vision devices or infrared detectors, should be tested in night operations. Such tests are critical in evaluating systems which use image intensifiers, because such equipment is subject to whiteout by muzzle flash, shell detonations, artificial light sources such as vehicle headlights, and other phenomena resulting in transient increases in local or ambient level of illumination.

All portions of the crew tasks cycle must be performed under conditions of reduced visibilities. Consequently, the test conditions must be duplicated in darkness as well as daylight. The measures of effectiveness do not change although additional instrumentation is required. Test conditions and measures of effectiveness are discussed under Objective 2; instrumentation is discussed under Objective 4.

(8) Vulnerability. Another influencing factor is the vulnerability of competing mortar systems to enemy fire. The amount of the weapon exposed, the weapon signature, and the duration of exposure are critical characteristics in estimating vulnerability. Weapon hardness is another consideration.

Normally with competing mortar systems, vulnerability will not be significantly different; each weapon system will require approximately the same amount of exposure time to secure position and will have approximately the same weapon signature. If this case exists, the vulnerability factor will cancel when weapons are compared directly. However, future developments may lead to indirect fire systems less vulnerable than present systems. The operational test should include a vulnerability check and a set of available measures for vulnerability. Exposure parameters should be expressed in terms of probability of detection and probability of being disabled given specified near misses from incoming rounds. The measures necessary to quantify these characteristics are discussed under technical Objective 2, which addresses the means of incorporating these influencing factors in the expanded service test.

(9) Closing Comment Concerning Objective 1. As a result of this analysis of influencing factors, several critical factors have been identified and should be considered in designing operational performance evaluations of Infantry indirect fire weapons and equipment. Since no field experiment has been run to test empirically the impact of these critical factors, a final recommendation is offered: each expanded service test should be considered a methodology study and the data should be used to validate empirically assumptions concerning critical factors and means of incorporating them. Those factors which prove to be of little value in discriminating between competing weapon systems can be de-emphasized from the test situation without loss in data validity. Others which prove to be important weapon system performance discriminators can be concentrated on providing improved test proficiency.

b. Technical Objective 2.

(1) Introduction. The second objective of the methodology study was to develop techniques and methods for measuring critical factors influencing weapon evaluation. The objective is stated below.

Develop the techniques and methods for generating meaningful numerical measurements of critical factors on a real time basis, i.e. determine instrumentation sample sizes, calibrations and controls, while permitting unimpeded tactical movement of the test soldiers in a reasonably realistic environment.

The approach recommended is to evaluate mortar system performance in a series of subtests which are to be sequential as if the series of subtests were a single test. The subtests are based on the crew task cycle described under Objective 1 above. Each critical factor is discussed in terms of a method for incorporating the factor into the operational evaluation. The activity described in sections (2.a) through (2.f) refer to evaluation of mortar systems under daylight firing conditions. Night performance evaluation is discussed in paragraph (6). The subtests and the evaluation plan which together comprise a summary in the form of a working format for weapon system performance evaluation appear in Appendix III. Consequently, Appendix III provides the recommended methodology for planning, conducting, and analyzing weapon performance. The rationale behind the recommendations in Appendix III appears in the following paragraphs.

(2) Deployment. Weapon system performance evaluation is based on the four tasks of the task action cycle--pre-mission activity, fire-mission, post-mission activity, and the transporting activity. The evaluation procedure consists of constructing a subtest for each of the basic crew tasks. The resulting four subtests provide operational performance estimates of candidate crew mortar systems or other indirect fire weapons that may be considered for adoption by the Infantry (e.g. pack howitzer). Each subtest is described briefly below along with its respective measures of effectiveness.

(a) Subtest 1. Pre-mission Activity. As outlined under Objective 1 above, this subtest requires the crew to place the weapon into action. Two types of measures are used: time-based measures and efficiency measures. The time-based measures simply measure the time required to complete each step in the setting up process. Included are times to unsecure and unload components such as the base plate, tube, ammunition and other equipment. Also included are set up times, weapon orientation times, and base plate registration times. The final action stops when the weapon is ready to fire the first round of a given fire mission. The overall time begins with the fire mission command or operations order, while the crew is in the transporting mode, to the time the first round is ready to be fired at the enemy. The subtest requires live rounds to be fired to seat the base plate. The subtest should be accomplished by rotating five mortar crews through four different firing points. Each firing point has a firing bed of different characteristics:

(1) Rocky, hard clay - level (Typical soil)

(2) Mud - level

(3) Sand - level

(4) Loose clay - sloping

Figure 2, Task Time Requirements, is an example of the data to be collected during each trial. The analysis consists of direct comparisons of mean values for each weapon system subtask and an analysis of variance test of the overall time to complete the pre-mission tasks. As described under Objective 4, data will be collected on video tape or film and times will be recorded while reviewing the record of action. A stop action capability is desired as well as a low-light level recording capability.

The second type of measure is a measure of crew efficiency and uses a crew drill analysis as shown in Figure 3. The form requires the analyst to review the pattern of work performed by individual crew members to determine how each crew member is employed while the weapon system is being prepared for action. A task chart is prepared from the recording. The purpose of the chart is to provide a direct comparison of the manner in which competing weapons are deployed. The chart is designed to identify cause and effect relationships. If one weapon is significantly more responsive, the chart may be used to determine if the improved responsiveness could be due to techniques of deployment or ease of deployment. Finally efficiency is measured by a Crew Member Work Form, Figure 4. The form is designed to show the exact contribution of each crew member in achieving weapon system performance level as measured by the responsiveness MOE. The ratio of actual work time to total time is the efficiency measure.

Figure 2

TASK TIME-REQUIREMENTS

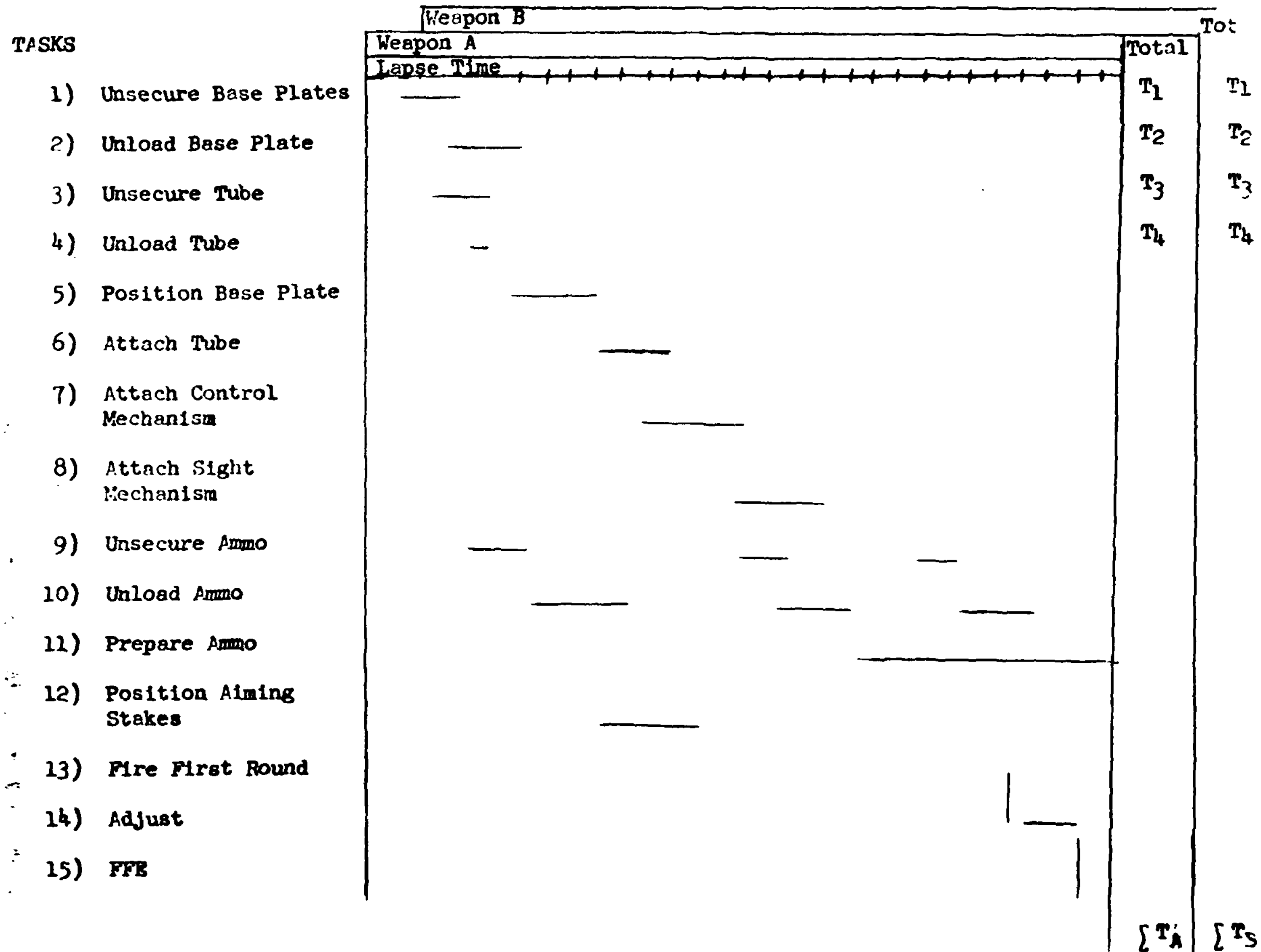


Figure 3

CREW DRILL ANALYSIS - PRE MISSION

Pattern of Work Participation

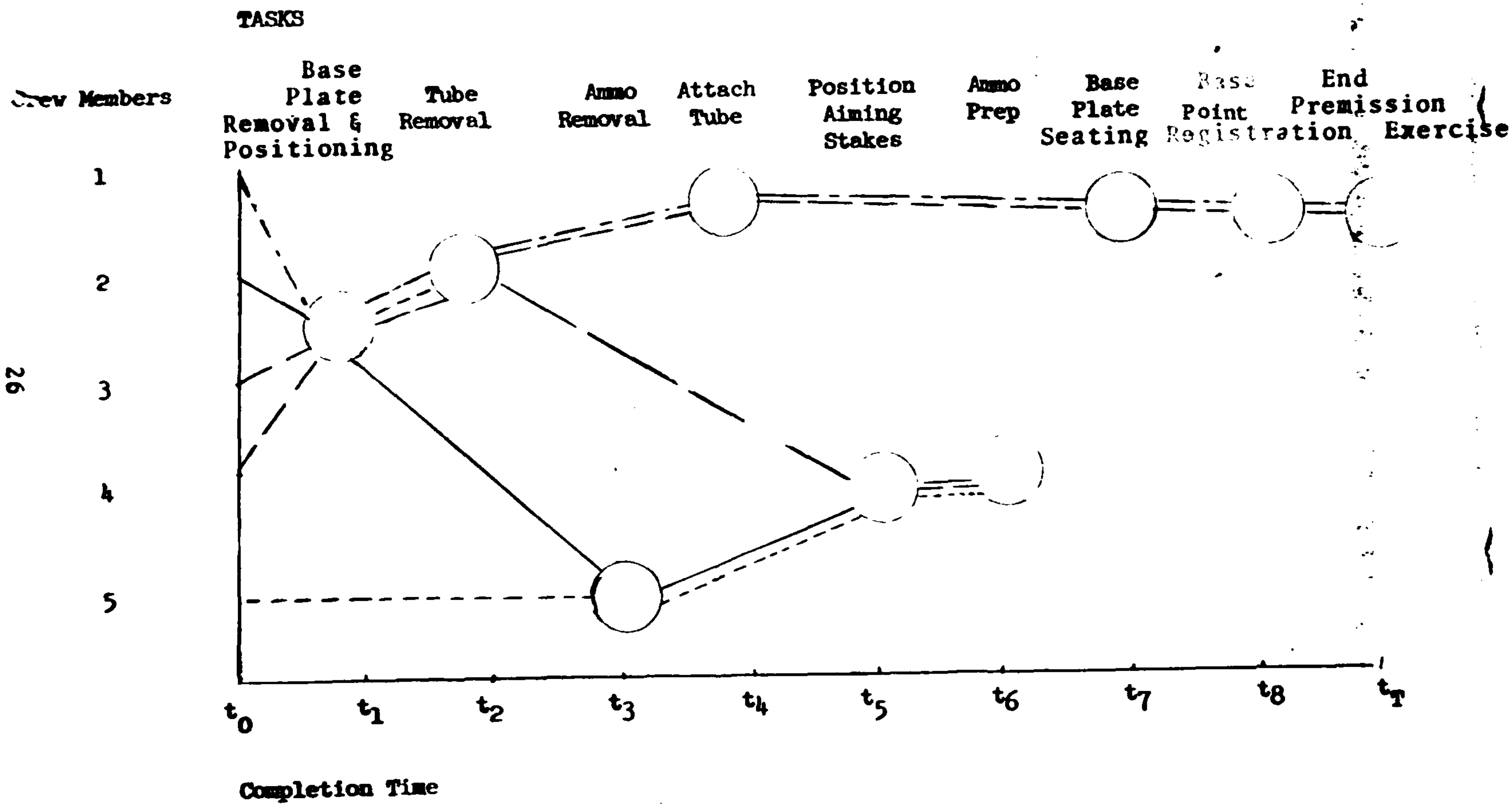
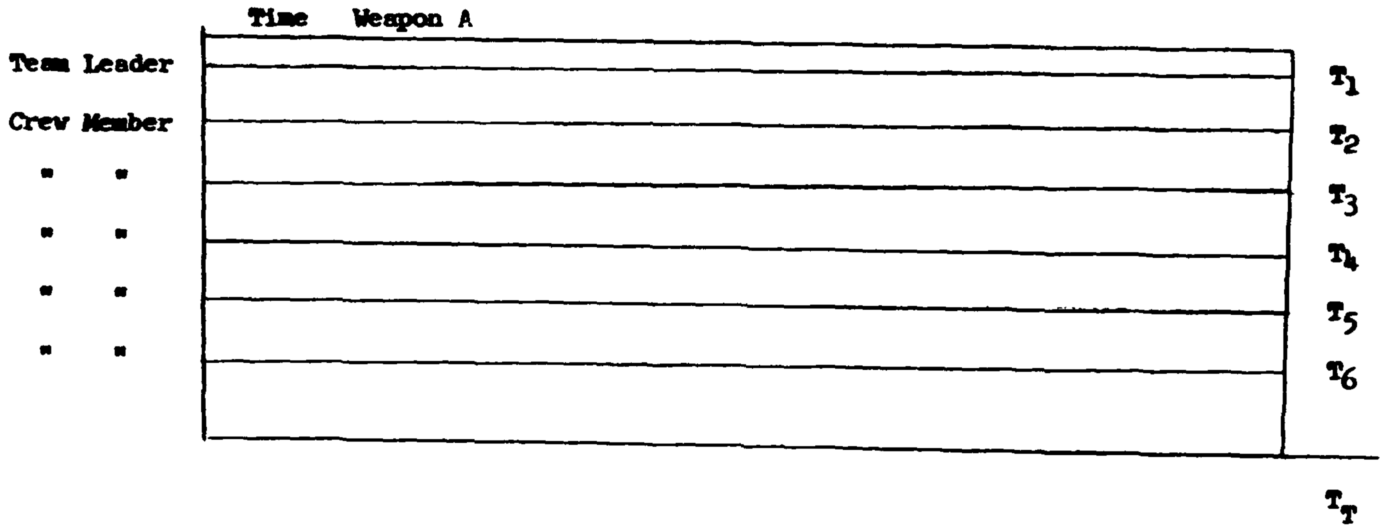


Figure 4

CREW MEMBER WORK LOAD



To complete this subtest, the pre-mission task should be completed a fifth time by each test crew using the rocky, hard-clay test bed. The task should be accomplished with one crew member removed from the crew. The three attached forms should be completed and responsiveness and efficiency measures compared. The ability to operate efficiently under handicap conditions is a distinctly advantageous weapon system characteristic. Analysis of the results of all four subtests is discussed under Section f.

Durability data are also collected during this activity; the procedure is discussed under the fire-mission activity, Subtest 2.

(b) Subtest 2. Fire-mission Activity. This subtest is designed to follow the preceding subtest without a break in time. The previous subtest is terminated with the firing of the first round of a fire mission; subtest 2 begins with the same event and ends with the last round of the final FFE command. The subtest is repeated five times during daylight with each crew, once for each of the four soil type/terrain conditions and once with the crew at reduced strength.

The subtest requires the crew to respond to three fire commands. The role of the FO and the FDC can be played in two ways: either through a series of canned messages or through the ADPE, assuming an automatic scoring system is available. The ramifications concerning the use of these two methods are discussed under Objective 4. The first command requires the mortar crew to take a simulated troop concentration under fire at medium range; the second requires a moderate shift in range and elevation to a new target (the base plate is not disturbed); and, the final fire command requires the crew to shift to a new target area. The new area is sufficiently far from the original area to require a shift of the base plate or a release and reattachment of the tube's T&E mechanism. (The target separation between fire commands 2 and 3 should be greater than 100 meters at 600 meters range; this distance will exceed the limitations of the traversing mechanism for the present mortar systems. However, future systems may require greater distances and the criterion should be changed accordingly.) Several types of measures are used: responsiveness, accuracy, stability, reliability, and durability.

(1) Responsiveness. Three MOE are used to gather responsiveness data during this phase of the test: time between rounds, time to shift fire, and number of adjustment rounds. Time between rounds, less time required for FO and FDC commands, measures adjustment time during fire for adjustment. Time between rounds is a measure of rate of fire during fire for effect. The measure is used as an indicator of potential crew/weapon/ammunition interface problems. It is involved with such tasks as ammunition preparation, base plate stability and subsequent correcting adjustments and mortar loading time. It is measured from the time the adjusting or firing command is given until the round is fired. Time to shift fire is a measure of the crew's flexibility in adjusting the weapon to fire at other targets. Two types of shifts are required: one target requires only a new setting on the T&E mechanism; the second target requires either repositioning of the base plate or release of the tube control mechanism to swivel the tube to the new azimuth. In either case, reaiming is required. The measure begins with the new fire command and ends with the final adjustment round.

It is emphasized that FO and FDC functions are handled administratively in order to remove this effect from the test design. It is felt that these functions should be controlled since erroneous commands could unnecessarily bias one weapon system.

(2) Accuracy. The ultimate test of any weapon is its ability to place effective fire in the target area. Measures used for indirect fire systems to determine this capability are rectangle of dispersion and offset error. The measure primarily applies to the rounds used in the fire for effect action. Rectangle of dispersion is a theoretical rectangle that encompasses all of the rounds in the FFE (see Figure 5). The offset error is measured from the theoretical center of impact to the center of mass of the target.

Dispersion itself is not an undesirable characteristic. However, it is essential to have some knowledge of the dispersion to compute range and deflection probable errors. By comparing actual probable errors to the data provided in the unabridged firing table, it is possible to determine weapon inaccuracies. Fifty percent of all rounds should land within one range probable error and the length of the rectangle of dispersion should be equal to eight times the probable error. Figure 6, in three parts, shows the desired result in terms of range and deflection rectangle.

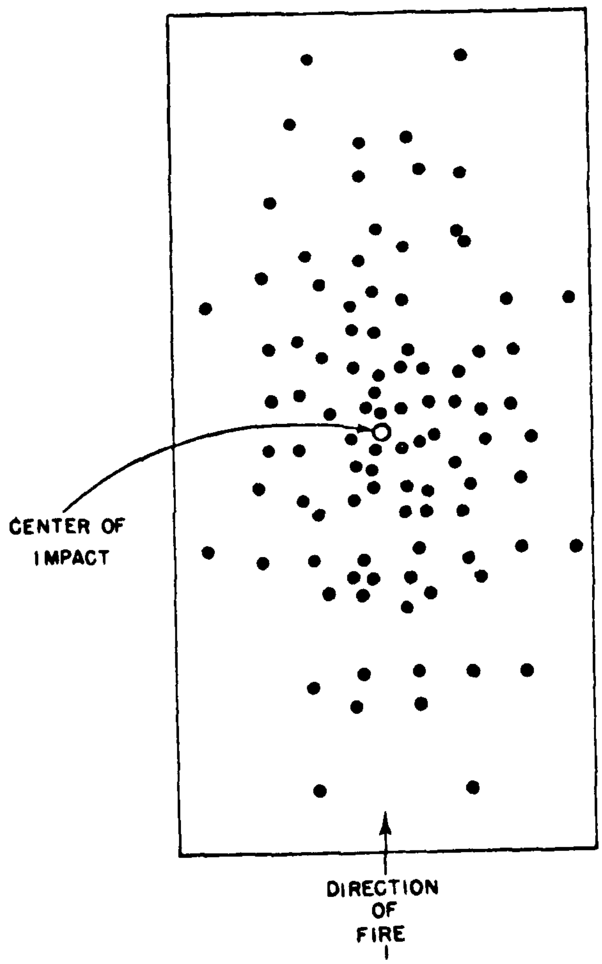
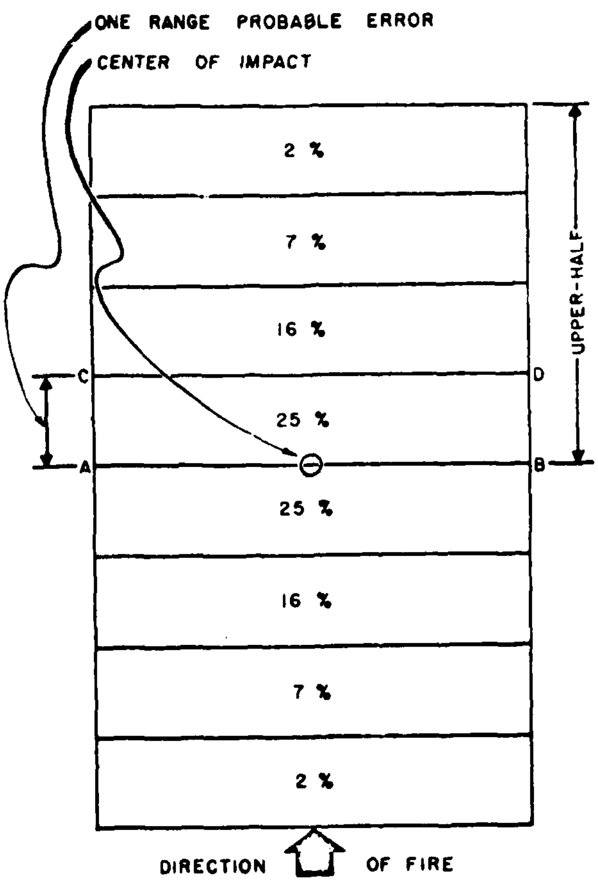
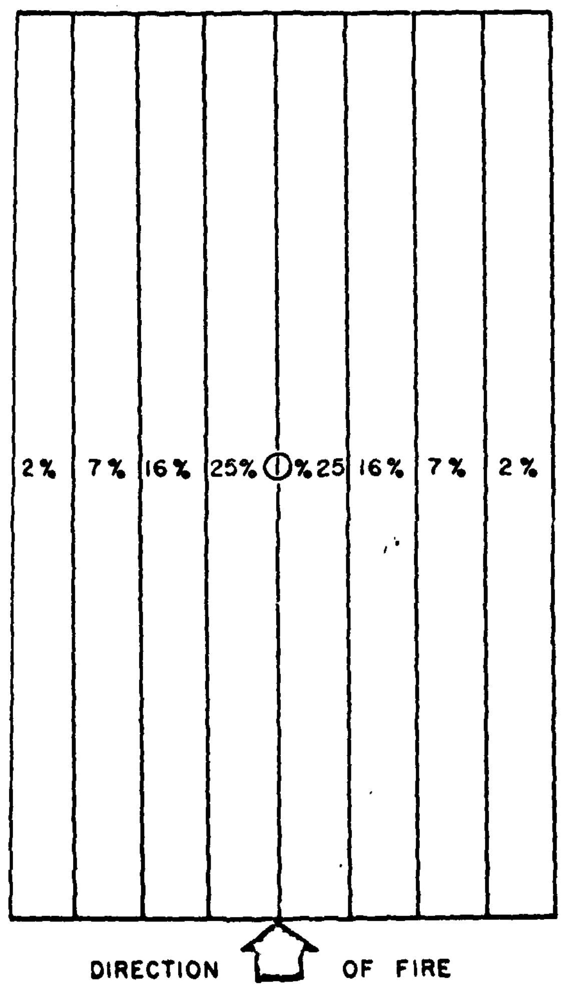


Figure 5. Rectangle of dispersion.

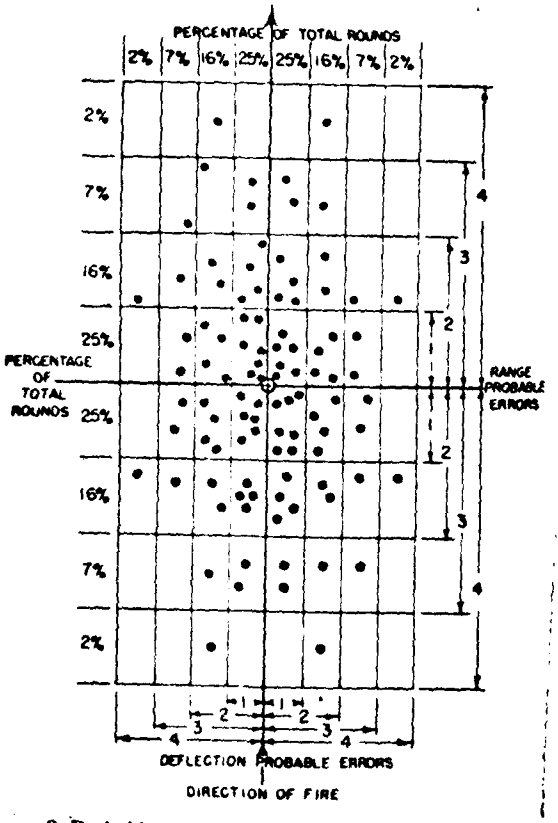


1 Range dispersion rectangle

Figure 6. *Dispersion rectangles.*



3 Deflection dispersion rectangle
Figure 6.—Continued.



2 Probable errors in dispersion rectangles

Figure 6.—Continued.

The mortar field manual shows several types of fire: destruction, neutralization, harassing, and interdiction. These variables are excluded from the operational service test of weapon system since they are more closely related to the terminal effects of the projectile. In all four cases, the responsibility of the crew and weapon, is to deliver the projectile from an unobserved position to the target area. For this same reason, targets may be simulated to the extent desired. Since the FO and FDC are handled administratively, the target area need only be equipped with reference points for measuring of offset error.

(3) Stability. Stability is tested by using four soil/terrain conditions. In each case, stability is measured by the number of adjustments, during the FFE action, required to maintain weapon orientation. Each adjustment to the T&E mechanism should be recorded as the crew members attempt to realign the weapon after each round. Also, total movement of the base plate should be recorded. This is accomplished by the use of reference markings adjacent to the firing position. Permanently positioned scales should be constructed on all four sides of the firing position configured in a 10-foot square. Measurements before and after FFE may be made by stretching a string between the measuring bars at a point tangent to the forward and lateral edges of the base plate. The differences in these measurements will provide a measure of the rearward and vertical shifts during firing. Other data concerning stability should be collected from subjective observations.

(4) Reliability. Reliability is measured by the number of rounds between malfunctions. These data are normally collected as part of the reliability subtest of the Expanded Service Test. Data during this phase of the service test should contribute to the overall reliability data base. These data should be entered in a gun book maintained by the test officer's representative. Normally, this book would be maintained by the weapon crew; however, since several crews will use each weapon system, the responsibility for reliability data must necessarily be with the test officer.

Another important aspect of reliability is misfire removal. Each crew will be subject to one staged misfire. Controller personnel will know when the misfire is to take place in order to time the removal. It is important that the mortar crews have no prior warning of a misfire and that all involved personnel treat a staged misfire as the real thing. The MOE to be measured is time of removal.

(5) Durability. This category is a measure of the weapon's ability to withstand the rigors of the combat environment. Component breakage should be recorded during the entire crew/task cycle, each time the system is removed from the carrier, set up, fired, dismantled, and transported. The measure is the number of breakages that occur and the types of breakages.

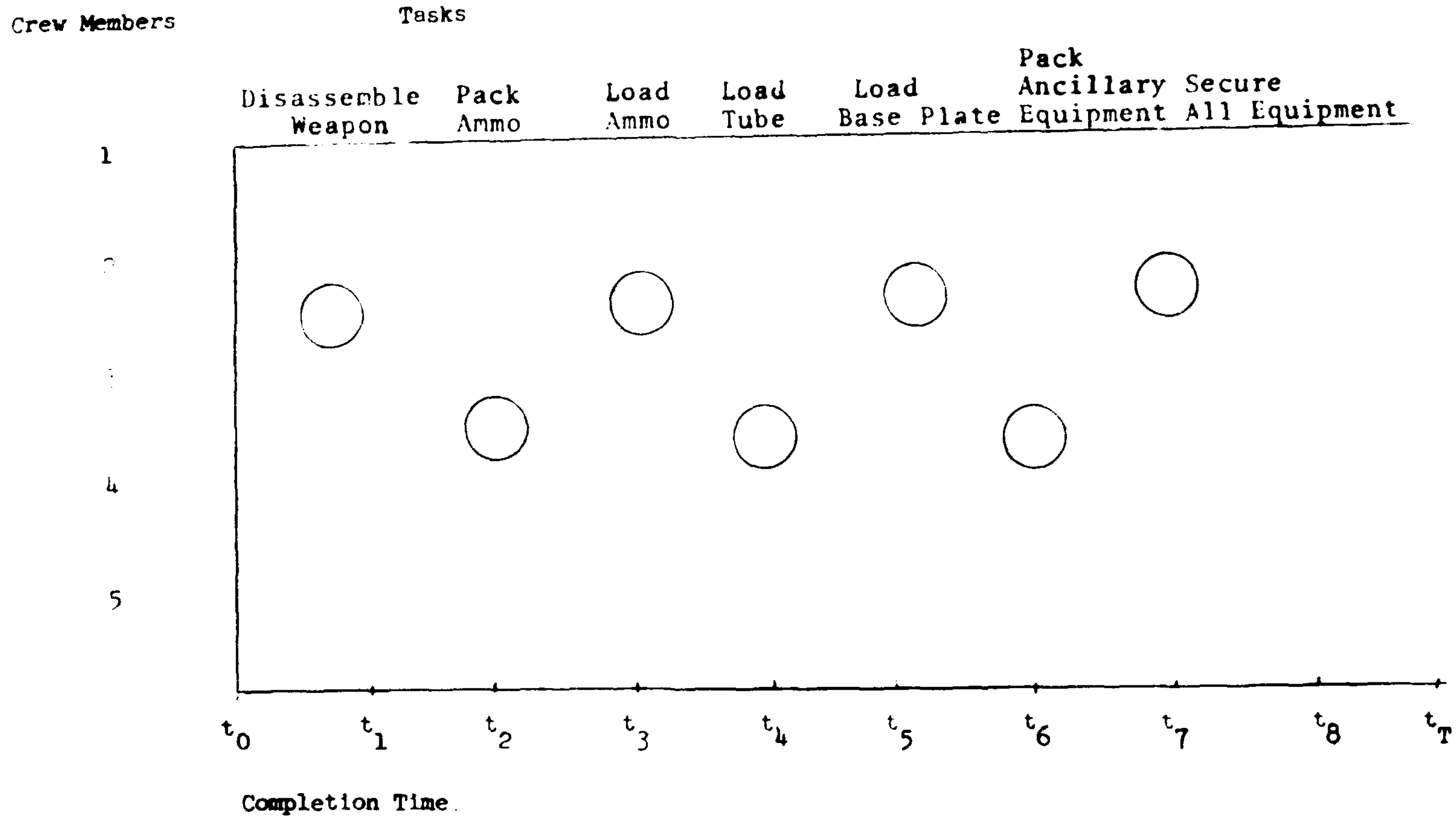
(c) Subtest 3. Post-fire Mission Activity. This stage of the crew task cycle is defined as the preparation for displacement activity. The weapon system has completed its fire missions and must prepare to displace to an alternate firing position. Specific tasks include: packing, loading and securing ammunition; disassemble, load and secure weapon components; and, secure ancillary equipment. Each crew will perform this activity five times during the daylight tests as the weapon is moved to different firing positions. Figures 2 and 4, which may be used directly for this subtest, show the MOE for this subtest. An additional figure, Crew Drill Analysis Post Mission, Figure 7, is required for this analysis. By combining results from Subtests 1 and 3, the responsiveness of competing weapon systems can be analyzed.

(d) Subtest 4. Displacement. The final phase of the crew/task cycle is displacement, which is a measure of the mobility/transportability of the weapon system. This becomes a viable category of effectiveness measures if the competing weapons use different transporting vehicles or are moved by personnel. In the case of vehicles, standard performance measures for vehicles should be used, especially those related to battlefield mobility. Cross-country speeds, as a function of terrain type, crew protection, and vehicle vulnerability are of primary importance. In the case of hand carried systems the CETF should be used to provide quantitative measures of effectiveness. Compatibility between weapon and carrier has already been accounted for in subtests 1 and 3 above. The actions of removing and stowing are measures of compatibility and are accounted for in the list of pre-mission and post-mission tasks.

(e) Integrated Subtests. Although it is possible to accomplish the entire crew/task cycle in a series of unconnected subtests, it is recommended that the test officer combine the subtests into an integrated series of tests which is treated by the crew as a single scenario. For instance, the test scenario should begin with the mortar set up in an

Figure 7

CREW DRILL ANALYSIS - POST MISSION



assembly area. The crew then receives an operations order to displace tactically to fire position A, take up position and prepare to support the conduct of the battle. The crew task action cycle begins with subtest 3 and is terminated by the final FFE at the third target. For each case, the next command is given just prior to completion of the previous command by the crew. For instance, after the order to displace and occupy a new position is given, the requirement for a fire mission is placed just as the base plate registration is taking place; the command to shift fire is given just as the FFE takes place on the previous target. The overall MOE is a mission accomplishment measure, time to complete fire mission modified by a set of accuracy criteria.

The mission accomplishment measure includes responsiveness, stability, reliability, durability and mobility/transportability. Crew drill must be accomplished quickly and efficiently to have a good mission accomplishment value; the time to complete mission is directly dependent on the cumulative time required to complete each subtask. If the weapon is not stable, extra time will be required for adjustments between rounds and will directly lengthen the mission accomplish measure. Malfunctions, a measure of reliability, will further lengthen the mean time to accomplish mission thus having a direct impact on the measure. Since the time to accomplish mission includes movement, lack of mobility/transportability will also impact on the selected MOE. The mission accomplishment measure in the subtests outlined accounts for all meaningful categories of effectiveness measures except accuracy. It can be assumed that area fire weapons are not highly dependent on accuracy. Fire commands originate from a forward observer who depends to a great extent on estimates. These estimates in turn are translated by the crew to adjustments in terms of reference stakes. The goal is to produce a set of rounds whose dispersion radius includes the target. The dispersion radius and its center of impact (which must be determined mathematically) are dependent on many factors including meteorlogical conditions, ammunition variability, observation errors, gunner/crew errors, and weapon characteristics. With this number and type of influencing variables, accuracy testing in the operational environment becomes extremely difficult. Engineering tests under highly controlled conditions are much more suited to accuracy evaluations. Engineering tests account for tube characteristics, weapon characteristics on a stable platform, and ammunition characteristics as a function of varying meteorlogical conditions.

The variables related to accuracy which are not included in engineering tests are FO and FDC errors and crew errors. Since fire control is common to all weapon systems, fire control errors can be eliminated from consideration. The remaining variables to be considered are the gunner/crew errors. The types of errors associated with gun crew actions are poor sight pictures, misadjustments to T&E mechanisms, and poor initial alignment of the weapon. These human errors are directly associated with the number of times these firing adjustments and T&E adjustments are made. Consequently, since time is required, these accuracy errors are included in the mission accomplishment measure.

Even though accuracy is related to the mission accomplishment measure, its relationship to mission success (accurate and timely fire when required) is such that it deserves special consideration in the analysis.

(f) Integrated Analysis. This section describes the analytical procedure for evaluating weapon systems. Basically, the problem uses two categories of measures: a mission effectiveness measure which incorporates responsiveness (crew drill, time to shift fire, etc.), stability, reliability, durability, mobility/transportability, and to a limited extent, accuracy. Another factor normally associated with weapon system testing is compatibility. This factor is not included per se since it is represented in the other categories of measures and is already an integral part of the mission accomplishment measure. Compatibility is concerned with such functions as:

Location and use of optical sights

Operation of traversing or searching mechanism

Movement from recoil

Placing the mortar

Loading

Ammunition storage

Weight of ammunition components

Interference between crew members

Each of these tasks has an impact on the responsiveness or the stability of the weapon and therefore is included in the existing MOE. The compatibility functions can be measured in terms of time to perform. Time to perform has to be considered in conjunction with expert opinion.

The integrated analytical procedure is complicated by the fact that the primary MOE, mission accomplishment, rectangle of dispersion, and offset error have widely varying characteristics. For instance, the mission accomplishment is a distribution of times while the rectangle of dispersion is a pattern of impacting rounds. To determine accurately the required sample size it is necessary to develop different sets of assumptions and constraints. Consequently, a multistage analysis has been developed.

The center of impact for each FFE action will be calculated for each weapon and then combined into a single overlay with the center of impact superimposed over a single point. With all rounds accounted for, the rectangle of dispersion will be calculated for each weapon type. If the distributions are significantly different, the superior weapon system will be that system whose rectangle of dispersion more closely approximates the theoretically desired rectangle of dispersion. This theoretical rectangle is sufficiently large to permit coverage with casualty producing fragments, but not so large that the weapon's effectiveness is reduced by gaps in the impact area. The theoretical rectangle is an area eight probable errors in range by eight probable errors in deflection (see Figure 6).

If a candidate weapon system fails to produce an acceptable rectangle of dispersion, it should be considered inferior and the analysis terminated. If no significant difference is observed, the analysis next considers the offset error. If the offset error is significantly different, that is, the target is on the average, well outside of the rectangle of dispersion for one of the competing weapons, the analysis should be terminated and the weapon with the smaller offset error selected. Termination at this point is justified because of the fact that significant differences occurring at this point are indications that the weapons are not close competing weapons. A significant difference in accuracy is a major weapon deficiency. Mortars are not designed to be used as accurate point fire weapons and the data were collected under conditions with many variables at work, such as meteorological conditions and ammunition variations. Finally, if there is no significant difference in offset error, the weapon can be considered equally accurate and the analysis should shift to a comparison of performance using the mission accomplishment measure. The mission accomplishment measure should resolve differences between weapon systems. Failure to resolve differences means that the weapons are very similar in performance and a detailed analysis of MOE should be made. The analysis may be terminated at this time if other considerations, such as cost of accepting a new weapon system, are paramount. If a decision is to be made on minor performance differences, the analysis proceeds using all MOE. In this case, weighting of importance of the various MOE becomes subjective. The procedure is outlined in Figure 8. Appendix III describes this procedure in more detail.

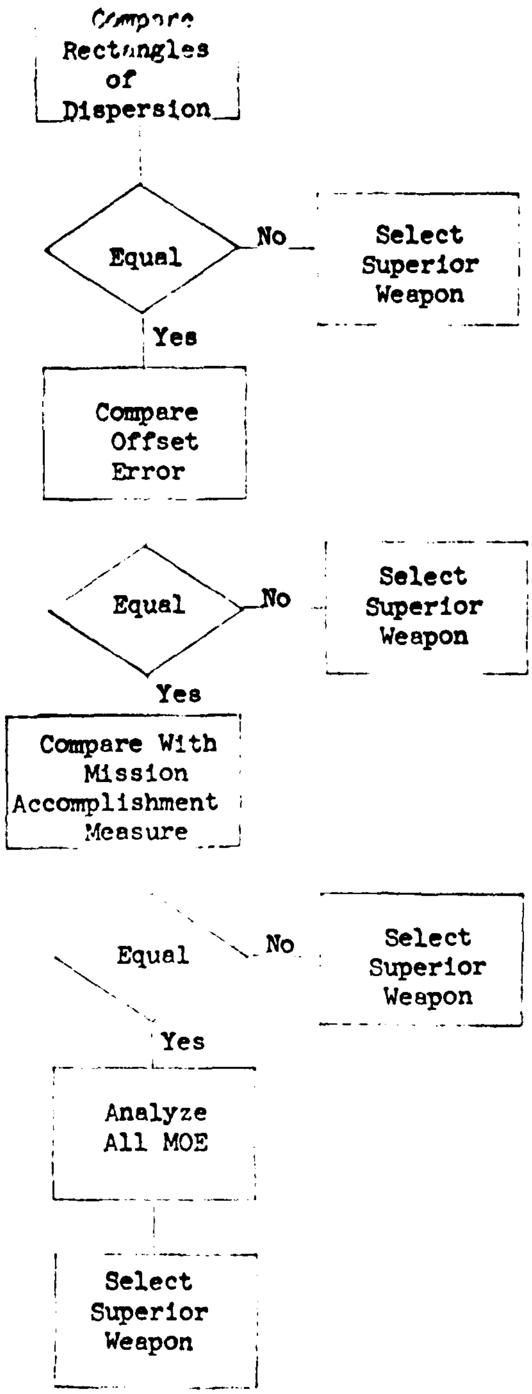
The subtests and analysis provide for the major experimental variables that should be considered in the operational service test. The paragraphs that follow will further discuss specific influencing factors and explain how these factors are accounted for in the test procedure.

(3) Human Factors. Several human factors were identified under Objective 1. Each of these factors is discussed in terms of incorporating the factor into the service test.

(a) Man-machine Interface. The influence of this factor is measured during the crew drill analysis in three phases of the task action cycle: pre-mission, fire-mission, and post-mission. Interface problems are measured by task completion times and are part of the cumulative measure of mission accomplishment, time to complete mission.

(b) Crew Proficiency. In a sense, the entire measure of mission effectiveness is a measure of crew efficiency. Further, direct comparisons between crews can be made in each mission subtask to insure that all crews perform within reasonable limits (1½ standard deviation from the norm). If specific crews are suspected of being substantially different in terms of proficiency, crew comparisons should be made with data generated by atypical crews removed from the data base.

(c) Combat Stress. Stress substitutes other than perhaps time pressure is excluded from the service test. It is felt that stress substitutes may have a negative impact on motivation and could reduce the crew's desire to perform.



ANALYTICAL FLOW CHART

Figure 8

(d) Motivation. Test crews should be alert and well motivated throughout the service test. They should be made aware of the time pressures and the importance of performing well throughout the tests. They should be encouraged to function as a team and should be trained together so that teamwork and camaraderie become a natural characteristic of the group. The teamwork concept is an important characteristic, especially when the team must function at reduced strength as required during a portion of the service test. Other methods of introducing realism are desirable; these include small arms simulators, artillery simulators, and combat equipment.

(e) Test Soldier Selection. The criteria used for selection of mortar crew members should be used for selecting troops without previous mortar experience. However, when possible, previously trained mortar or artillery personnel should be used since mortar training consists of much more than weapon familiarization. The individual should be familiar with the concept associated with firing at targets, which cannot be seen through a series of reference points. Lack of familiarity with indirect fire procedures dictates a much more comprehensive training program.

Crew members should be representative of the entire population of mortarmen. Particular attention should be paid to size, IQ, visual and aural acuity, and dexterity. With respect to measurable characteristics, such as height or weight, the cut off should be 1½ standard deviations from the population mean. The test officer should watch for other less measurable traits, such as, ineptness, clumsiness, or lack of dexterity.

(f) Attrition of Crew Members. Each crew will be required to perform the fire mission with one crew member removed. The reduced crew will fire from only one soil condition. The test and control crews will be matched with respect to the particular member removed. The analysis procedure will be separate from the regular analysis and will be either a t-test or a simple analysis of variance.

(g) Sample Size Requirements. Considerations for the determination of sample size are many and varied. Two major problems exist in determining the number of crews and weapons requested to create an adequate data base: the sample of FFE patterns must be determined as well as the distribution of times to accomplish the mission. The analysis which determined that a sample size of 20 test crews would be sufficient to find a 20-second difference in performance appears below. The five replications of three FFE actions for each crew of the 20 crews will produce sufficient patterns to determine rectangle of dispersion.

In a test of mortar systems in which the primary objective is to determine whether a candidate mortar system is more effective than an existing system and the secondary objective is to measure the performance of the candidate mortar system, there are both operational and statistical factors which must be considered in selecting the sample size.

(1) Operational Factors. From an operational viewpoint, the selection of sample size is constrained by:

(a) The desired confidence in and accuracy of experimental results.

(b) The magnitude of the differences (improvements) in performance which are considered to be militarily significant.

(c) The availability of time and resources to support the test.

(2) Statistical Factors. The foregoing considerations translate into the primary statistical terms α, β, Δ, and n; they are discussed below. These are the experimental risks in making comparisons.

There are two kinds of wrong decisions that can be made on the basis of experimental data; the probabilities (risks) of making wrong decisions are denoted by α and β where α is the probability of concluding that the candidate mortar system is better than the existing system, when, in fact, there are no differences of military significance. The consequence of such a false finding could be the procurement, at considerable expense, of the candidate system even though it provides no real advantages; α, therefore, may be termed the cost risk. Further, β is the probability of failing to detect a true, meaningful improvement in the candidate mortar system over the existing system. The consequence of such a false finding could be the failure to procure the candidate system, thereby denying forces in combat an improved capability. β, therefore, may be termed the operational risk.

If, in setting the acceptable risks for an experiment, α and/or β must be held low, a relatively larger sample size is required than if α and/or β can be relaxed and higher risks accepted.

For a given set of experimental risks, the sample size (n) required to detect statistically a specified improvement in one system over another depends not only on the difference of interest (Δ), but also on the type of MOE which is being used to make the comparison.

If the MOE is a proportion (e.g., percent of targets hit), Δ becomes the difference between two proportions (θ_1 and θ_2). If the lesser of the two proportions which are being compared is expected to be near the bottom of the scale (e.g., $\theta_1 = .10$), a smaller sample size will be required to detect a specified difference (e.g., $\Delta = \theta_2 - \theta_1 = .30 - .10 = .20$) than if θ_1 has a somewhat higher value on the scale and Δ retains its same value (e.g., $= \theta_2 - \theta_1 = .40 - .20 = .20$). The same relationship holds true when θ_1 and θ_2 are in the upper half of the scale. The largest sample size is required at the mid-point of the scale (e.g., $\Delta = \theta_2 - \theta_1 = .60 - .40 = .20$).

If the MOE is a continuously distributed variable (e.g., time to fire for effect), the specified difference must be considered vis-a-vis the expected variability in system performance; Δ is, therefore, usually expressed in units of the standard deviation (σ), and the ratio Δ/σ is established. If Δ/σ is small, a greater sample size is required (in a relative sense) than if Δ/σ is large.

In making comparisons, the value of (n) is sensitive not only to differences of interest (as discussed above), but will also vary depending on the confidence ($1-\alpha$) and accuracy (expressed in terms of the limit(s) of a confidence interval) with which it may be desired to make statements concerning a true difference in performance (Δ_t), given an experimentally observed difference (Δ_o).

For the secondary objective of the experiment, which is concerned with only the candidate mortar system, the statistical terms (β and Δ) do not apply. Confidence ($1 - \alpha$) and accuracy (confidence interval) become the terms of principal interest. As the desired confidence in accuracy of experimental results increases, so will the required sample size increase. When considering a proportion (θ), its true (θ_t) and observed (θ_o) values are of concern. It is frequently convenient, when dealing with a continuous variable, to express the confidence interval in units of (σ).

The relationships of (n), the sample size, to selected values of α, β, θ_1, θ_2, Δ/σ, $(1 - \alpha)$, Δ_t, Δ_o, and confidence intervals are discussed further and illustrated in Figures 9-13.

(3) Steps In Selection of Sample Size. Primary consideration is given to providing, within available time and resources, the best comparison of the candidate mortar system and the existing system.

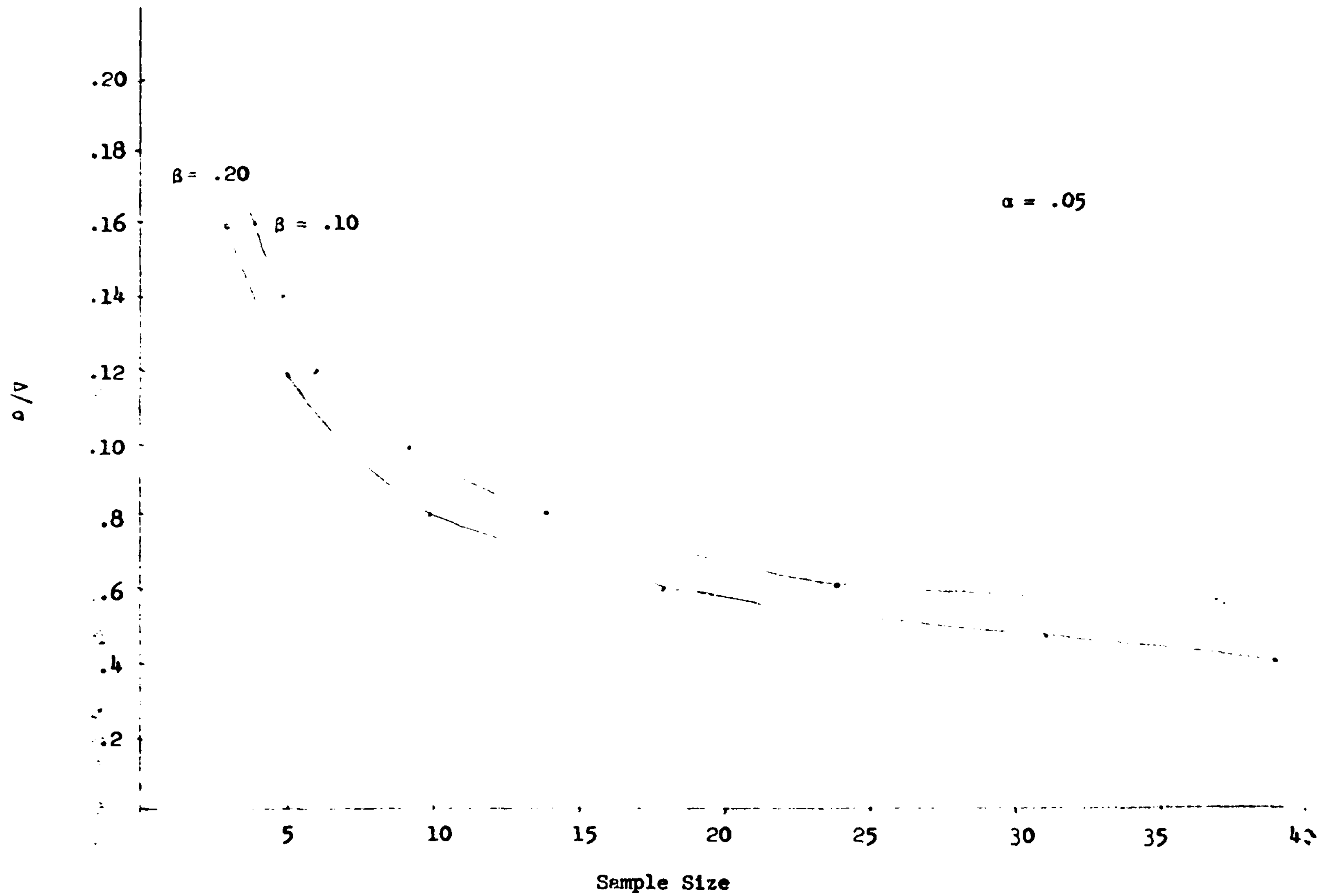
The design goal is to hold both the experimental risks (α and β), as low as possible. Of the two, however, the operational risk, β, is considered the more important; in the event trade-offs become necessary, the α risk could be relaxed, but not the β risk.

The specific measures to be used in comparing system performances were identified and, for purposes of experimental design, a value (difference in performance, Δ) which was considered militarily significant was associated with each of the comparative measures. The militarily significant measures were formulated into the experimental MOE.

The primary MOE, time to fire for effect has been selected as the design MOE, i.e., the design of the experiment will be based on a sample size not less than (n) most appropriate to this MOE. Figures 9, 10, 11 show, with β set at .10 and .20, the trade-offs among representative values of n, Δ/σ, and α.

(a) Under the assumption that an operational error is more critical than a cost error choose $\alpha = .15$ and $\beta = .10$. Other values of α and β can be chosen; however, smaller values will result in larger sample size requirements. Larger values will result in a smaller sample size but the precision of the experiment is less.

(b) No firm estimates of how long it takes to fire for effect exist. However, when asked this question knowledgeable personnel indicated from 2 to 5 minutes depending, of course, on a multitude of factors. Techniques exist for estimating the standard deviation from the range. The estimate procedure is generally recognized as reasonable for $n \leq 10$. The larger n becomes the less efficient the estimate becomes. It will be guessed that a sample size of approximately 16 is adequate. The range, taken as 3, is then divided by the value 3.532 to estimate σ. The estimate thus obtained is .85 minutes.


Δ/σ
.20
.18
.16
.14
.12
.10
.8
.6
.4
.2
β = .20
β = .10
α = .05
5
10
15
20
25
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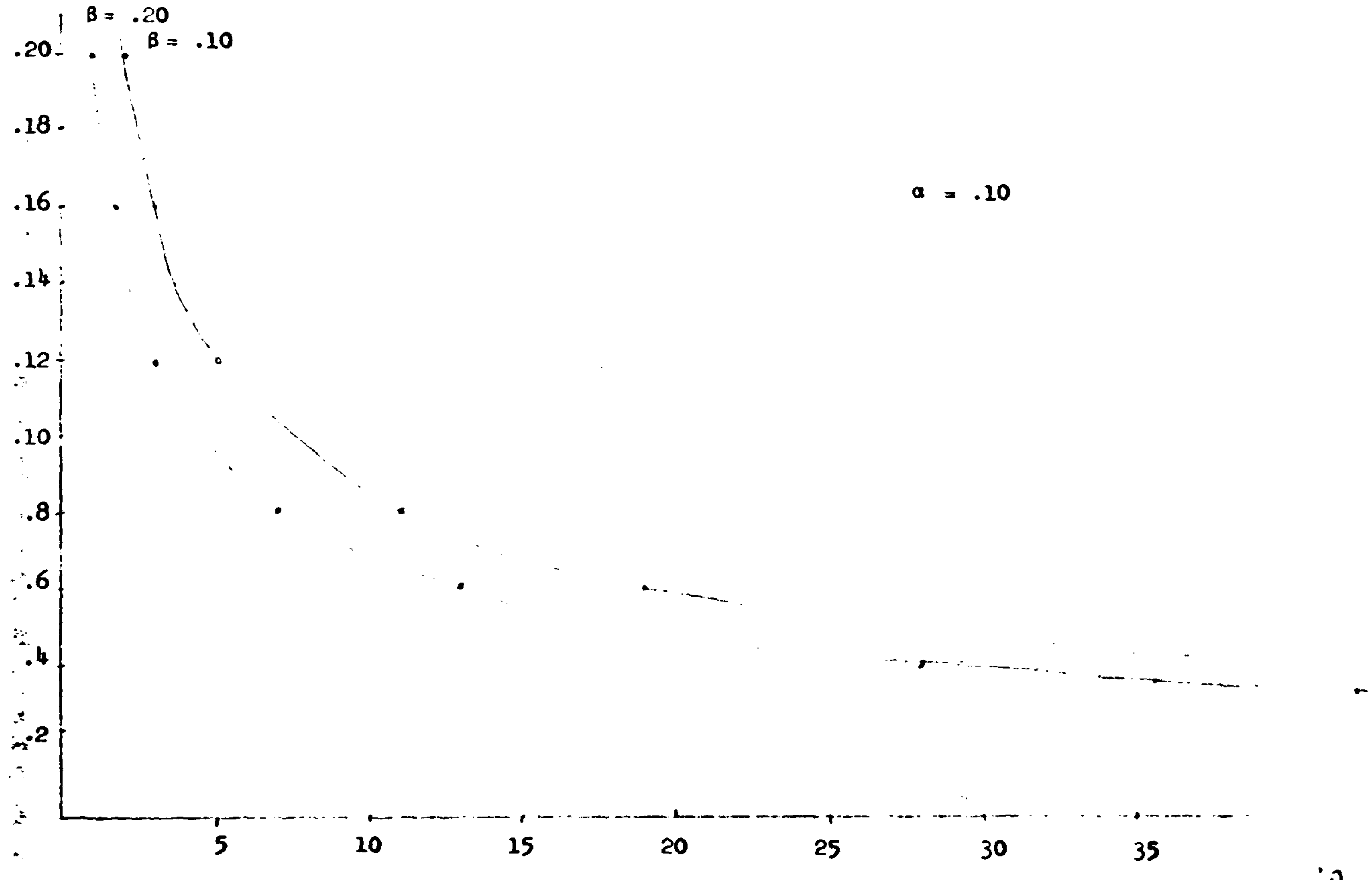
35
40
Sample Size

Figure 9


β = .20
β = .10
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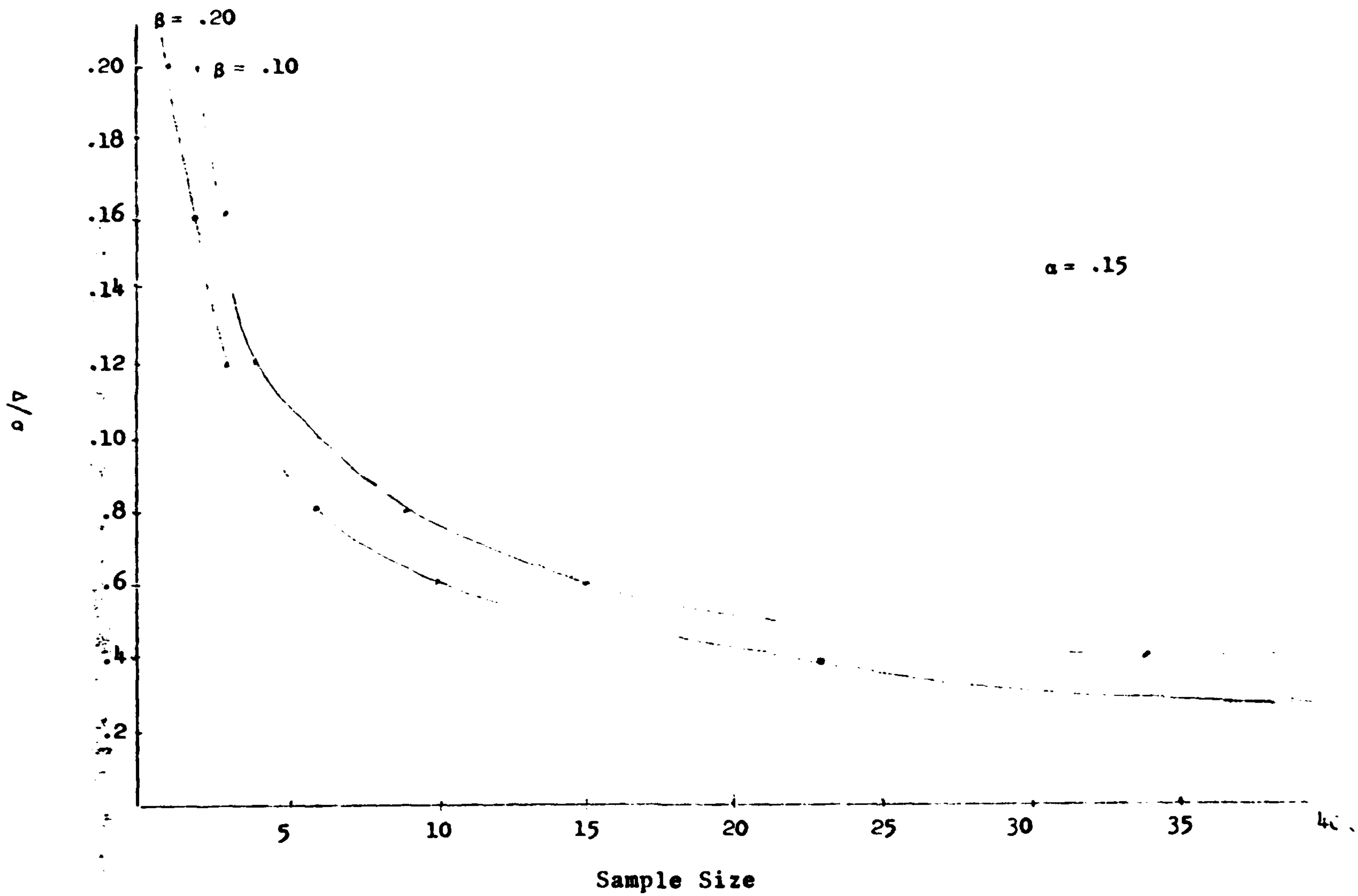
Sample Size
Figure 10


β = .20
β = .10
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Sample Size

Figure 11

(c) Given that the estimates are reasonable approximations, it can be seen (Figure 11) that approximately 23 test crews are needed to detect a difference of 20 seconds. The original estimate of σ was based on a sample size of 16 and the approximated sample size is a little higher. A sample size of 20 test crews should be adequate.

(4) Sensitivity of the Sample Size. The extent to which the sample size will satisfy the design MOE will depend on the differences in performance which are actually observed in the experiment. If the observed differences are equal to or greater than predictions, the sample size will be adequate, and the accuracy associated with any given confidence level will increase as the differences increase. If the observed differences are less than predicted, the reverse will be true. Dependent on observed differences and standard deviations, the sample size may or may not be adequate to find statistically significant differences at the desired confidence level for other MOE, e.g., rectangle of dispersion.

(5) Adequacy of Sample Size for Confidence Intervals. The selection of the sample size of 20 as optimum was dependent on many estimates concerning influencing parameters. If measurement of the performance of one system, rather than the comparison of two, is the issue, different trade-off curves are used.

For the confidence interval for a continuous MOE, Figure 12 is appropriate. Enter with n on the horizontal axis, read to the α curve, and move left to the vertical axis to find the length of the confidence interval. For example, with $n = 20$ and $\alpha = .15$, the length of the interval will be less than 1_{σ}. In other words if σ is assumed to be .85 minute, then the confidence interval which includes the true mean will be less than .43 minute on either side of the assumed mean value of the MOE. If the assumed mean were 3.6 minutes, the statement could be: "85 percent confident that the true mean lies between 3.17 and 4.03 minutes."

Again if the confidence accuracy obtainable with $n = 20$ is not acceptable, additional time and/or resources will be required for the experiment, but it should be realized that quantum increases in n must be accepted to increase confidence accuracy appreciably.

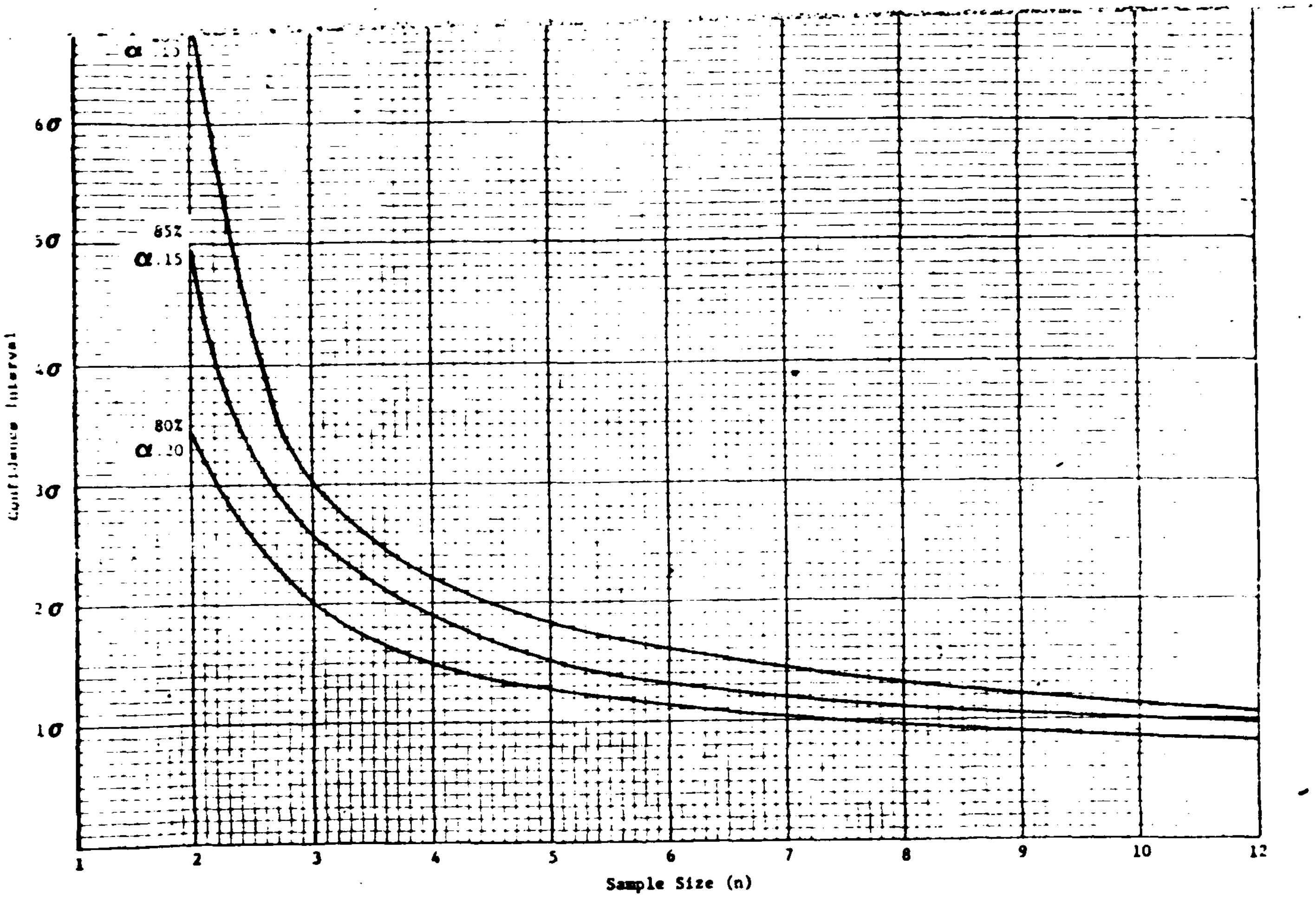


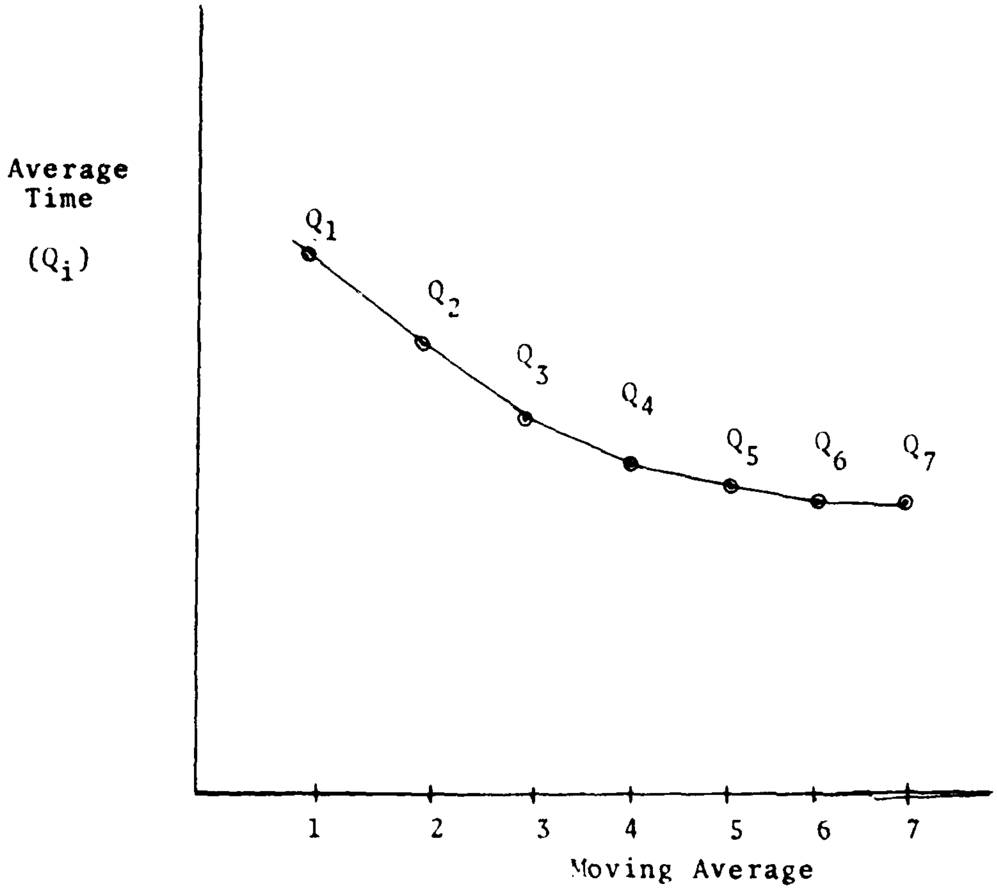
Figure 12 EXPECTED CONFIDENCE INTERVAL LENGTH FOR THE MEAN OF A NORMALLY DISTRIBUTED RANDOM VARIABLE

(6) **Training.** Selection of valid MOE to determine level of training is a difficult task. No empirical training study data are available from which MOE can be derived. This problem has been identified as a subject for future study by the USAIB. Meanwhile, responsiveness measures have been selected as a measure of training proficiency. Individual events in repeated training exercises should be timed. As crew and individual proficiency increases, the time to accomplish specific tasks shall stabilize. Two phenomena should occur: the time to accomplish the task should cease to improve and the standard deviation should reach a minimum value. Consequently, a moving average technique should be used to compute the mean values and the rate of change should approach zero or a very small figure. Time to first round has been selected as the MOE to measure crew proficiency. The procedure will be to take the arithmetic average of the first three trials (Q_1); calculate Q_2 by computing the average of trials 2, 3, and 4; and in general compute Q_i by the relationship

$$Q_i = \frac{X_i + X_{i+1} + X_{i+2}}{3}$$

where X_i is the observed time to first round on the i^{th} trial. The Q_i's will be plotted in a fashion similar to Figure 13. Training will be terminated when $(Q_{i+1} - Q_i) = (Q_i - Q_{i-1}) \pm .05\ (Q_i - Q_{i-1})$. That is when the improvement in performance is less than or equal to five percent, the crews are considered sufficiently trained. The five percent criterion is rather arbitrary and a visual inspection of the graph may be all that is required to adequately determine training. To safeguard against the possibility of a step function whose plateaus cover several moving average points, at least ten trials should be performed before comparisons are made.

(7) Terrain. Four types of terrain (soil/topology) have been selected for the indirect fire weapon system evaluation. Each of four prepared firing positions will have different soil/topological conditions. Position 1, which will be used for both day and night tests as well as firing at reduced crew strength, will be composed of hard clay mixed with small to medium sized rocks. The site should be level and approximately 20 x 20 feet. The site should be large enough to accommodate the entire crew while they are performing all pre and post-mission tasks. Position 2 and 3 should be the same size, should be level, and should be composed of sand and mud, respectively. The base material should be at least 5 feet deep to permit the base plate to settle as it normally would. The prepared mud site should be soaked with water for 3 days prior to its use so that a uniform consistancy will be maintained from test to test and at different times of the year.



Time to first round as a moving average (period 3)

Figure 13

Site 4 should have a gentle side slope of approximately 6 degrees. The soil should be loose so that the area may be leveled with a moderate time penalty if the system cannot cope directly with the slope. Each firing position should be administratively cared for to insure identical conditions when each weapon system arrives. No weapon system should benefit from preparation efforts of the previous occupants.

(8) Night Operations. To test the capability of competing weapon systems to perform under conditions of reduced visibility, the entire test scenario should be repeated at night using firing position 1. The crew should be at full strength. Procedures that are normally used at night should be employed during the test. The MOE do not change if instrumentation is available to collect data under night conditions. Test procedures for ambient light and artificial light should be the same. Additional data required include light level data. Instrumentation requirements for night testing are discussed under Objective 4.

(9) Vulnerability. Although indirect fire teams do not normally come under direct fire, vulnerability can at times be a factor. The test officer should attempt to compare the exposed areas, exposed times, and weapon signatures of competing mortars. In cases where the vulnerability of competing factors is different this factor must be taken into consideration. Vulnerability to indirect fire should be evaluated in terms of exposure to overhead bursts.

The vulnerability model described in Volume II for anti-tank weapons may be used for indirect fire weapons. The ratio model is of the form:

$$\left(\frac{A_1W}{A_2W}\right)^a \left(\frac{B_1X}{B_2X}\right)^b \left(\frac{C_1Y}{C_2Y}\right)^c \left(\frac{D_1Z}{D_2Z}\right)^d = \text{Vulnerability}$$

where A, B, C, and D are numbers for the area exposed to direct fire weapons, time exposed, area exposed to indirect fire weapons, and signature (W, X, Y, Z); and a, b, c, and d are the order of importance as determined by the test officer. If all four factors were to be considered equal, all exponents would simply be set equal to 1. Any set of measurement scales may be used for these factors since the scales cancel out of the equation.

This model does not represent the probability of being detected, but, since it incorporates the influencing factors in mortar detection, it is directly related. The use of the model will permit inclusion of these factors in the decision process.

(10) Closing Comment Concerning Objective 2. This effort has been an attempt to describe procedures for insuring that influencing variables are a part of the operational service test of indirect fire weapons. Future testing will provide quantitative data to estimate the adequacy of the MOE described for use herein. The development of the prescribed measures will reduce to a minimum the subjectivity in expanded service testing. However, some subjectivity will always remain. The subjective areas of immediate concern are discussed in the next sections.

c. Technical Objective 3.

(1) Introduction. The third technical objective of the Infantry Weapons Test Methodology Study is concerned with subjective evaluation factors. It is stated below:

> Attempt to isolate those factors which are subjective and are not amenable to measurement from those which are, and establish the relative importance as contributing to effectiveness. The use of interim "breadboard" facilities is desirable to determine the feasibility of testing methodology, and to explore variables and techniques. These devices will utilize movable structures, basic electromechanical devices and instrumentation. Existing computer or programer capability will be used when available for supporting the study and determining permanent requirements.

Several factors have been identified as being subjective in nature. (1) There is not any good method of weighting various MOE in the decision process. Although crew drill can be timed and evaluated to determine efficiency factors, causes of excessive times are somewhat subjective especially when a time measure is used that covers several events. (2) Stress factors have been identified as being subjective as has (3) the quality of training for individual weapon systems. (4) The assignment of weights to the various parameters in the vulnerability model is subjective action. (5) Finally, the selection of combat actions is a subjective factor; weapon system performance is evaluated in the operational service test while the weapon is performing specific combat actions and tasks. Consequently, the evaluation of performance, although measured and analyzed objectively, is dependent on the task being performed. Each of these subjective factors is discussed briefly below.

(2) Weighting MOE. Discussion of MOE under Objective 2 provides the rationale for weighting the three primary MOE: offset error, rectangle of dispersion, and mission accomplishment. In addition to these performance measures the decision maker must also include in the decision the effects of reliability as measured by the number of rounds between malfunctions, stability, and durability. In comparison with engineering reliability tests, the number of rounds fired during an operational performance evaluation is relatively small. The sample is not conducive to pinpointing small performance differences between weapons. Consequently, if problems are found with respect to reliability or durability, there are very serious implications and these considerations should take precedence over accuracy or responsiveness measures. If no significant differences are found in reliability or durability, the analyst should next consider stability. This measure is treated subjectively to the extent that stability problems cause minor crew delays while individuals make extra adjustments or attempt to compensate for lack of stability; the observer/test officer should be alert to causes of long responsiveness times. These causes are, for the most part, subjectively identified.

(3) Stress and Motivation. To summarize the rationale which appears under Objective 2 above, time stresses and battlefield realism should be applied to the test situation to the extent possible. Stress substitutes such as fatigue should not be used since it fails to produce the type of reaction associated with fear in combat and may otherwise reduce the test crew's motivation to an unacceptable level. Several studies are presently underway to gain better understanding of such stress factors as suppression. Perhaps these studies will lead the way to improved methods of incorporating stress into the service test.

(4) The Vulnerability Model. The four major factors in the vulnerability model must be weighted subjectively if vulnerability varies sufficiently between test weapons to become a factor to be considered. The factors are area

exposed to direct fire weapons, time of exposure, area exposed to indirect fire weapons, and weapon signature. The relative importance of these factors will vary from one tactical situation to another and will depend on the ability of the enemy to employ sophisticated location devices such as IR sensors or seismic systems. Normally vulnerability differences between existing mortars will be negligible and need not be considered. If differences exist, the importance of each factor in the vulnerability equation must be determined subjectively.

(5) Selection of Combat Tasks. The Indirect Fire Weapons Methodology Review describes combat actions. However, the review shows that specific crew tasks do not materially differ from one combat task to another. The basic crew/task cycle must be performed in each combat action. Emphasis has been placed on those combat actions which require mobility; static actions, such as a deliberate defense, receive less weight during the evaluation since much of the evaluation is based on set up and orientation procedures. This weighting toward combat actions which require movement is compensated for, at least partially, by the weighting of the MOE during analysis. Weapons are initially compared in terms of accuracy and, if no significant differences are found, the comparison is made on the basis of responsiveness.

(6) Closing Comments Concerning Objective 3. Due to the nature of indirect fire weapons, many objective factors play a less important role in weapon system evaluation. Crews are less apt to be under direct fire and, consequently, suppression and stress are less important. The tasks of the mortar crew are less varied than the tasks of direct fire weapon crews and, consequently, the selection of combat actions is less important. In general, fewer MOE are used for indirect fire weapons simplifying the analytical process. The one area which plays an important role is the identification of cause and effect relationship. There is much activity at the mortar position during firing. The measures are relatively gross measures of overall effectiveness. Consequently, the relating of poor performance as identified by the MOE and the causes of the poor performance place a large burden on the test officer and his observers. To assert in this task, the observers are asked to make many smaller measurements: times for individuals to perform subtasks. These times should help identify poor performance, but, due to the activity at the test site, these

times are difficult to measure accurately. If these small measures are to be gathered by observers to reduce subjectively in determining cause and effect, a recording medium such as film or video tape will be mandatory. Instrumentation requirements are discussed in the next section.

d. Technical Objective 4.

(1) Introduction. The fourth technical objective of the methodology study is oriented toward the development of automated test facilities on which operational performance may be measures. The objective is stated below:

> As a final objective, the foregoing results are eventually intended for application to automated ranges which will permit imposition of programed field operational tests while recording and analyzing test data and displaying results with a minimum of maintenance and technical support.

Due to changes in the methodology study, this objective for indirect fire weapons was eliminated in favor of a study of grenade launcher weapons. Grenade launchers were not covered in the original study program because of their more recent development.

Much work has been accomplished which can be related to indirect fire weapons. These studies will be described briefly in the following paragraphs to substantiate recommendations concerning types of instrumentation which is deemed necessary for an automated test facility.

(2) Test Concepts. The basic concept is to develop a scenario which requires the weapon and crew to take a set of targets under fire from four different firing positions. At each position, the crew must go through the entire crew/task cycle: pre-mission, fire-mission, post-mission, and movement or transportation. These actions are common to all combat actions. While the crew performs these tasks under controlled conditions with prototype and standard weapons, measurements will be taken which describe quantitatively the crew's capability. Appendix III describes the test procedure in detail.

(3) Data Required. The following data are required for evaluation of crew/weapon performance as a function of weapon type, individual crews, and firing position:

Off-load and set up times

Registration times

Impact location

Collapse and load times

Movement times

Reliability data

Several instrumentation systems are required to gather these data without infringing on the freedom of movement of the individual crew members. Two test facilities are described. One facility is within the current state of the art but provides few measures, poor data resolution, and more administrative time for data collection. The second system is fully automated but requires development and procurement of several instrumentation subsystems.

(4) Recommended Method for Current Testing. Current testing methods can be applied to each of the tasks in the crew/task cycle to provide the necessary data. The methodology for each task is outlined below; however, the entire test can be a continuous process with one task beginning as the previous task terminates. The scenario begins with the mortar set up. An operations order is issued requiring movement to the initial firing position.

(a) Post-mission Task. With the crew in position the test officer or observer issues the operations order and begins the timing and data collection process. Stop watches may be used to measure the lapse of time from the issue of the order until the system is ready to move. TV or movie cameras should photograph the entire process. Repeated reviewing of the film or video tape will produce the times to complete each subtask and the time each new member was actively participating in the post-mission task.

(b) Transportation Task. If identical vehicles are used for each weapon system the observer need only ride with the system to determine if vehicle/crew/weapon compatibility problems exist. The observer must subjectively determine if the tie downs or fasteners for equipment are adequate, or whether cross-country travel causes damage to any of the system components. In the case of different vehicles, travel times should be measured. Lapse time to the new position is the measure required.

(c) Pre-mission Tasks. Using procedures similar to those used for post-mission tasks, off-load, set up, and registration times must be measured. An automatic round count can be used to measure the number of rounds to seat the base plate and register the weapon. Stop watches can be used to measure the lapse time from vehicle stop until the system is ready to fire the first round of a fire request from the FDC. Film or video tape should be used to record individual crew member activities. Repeated viewing may be required to gather times for subtasks. The data required are the times to accomplish specific tasks, as described under Objective 2, and the number of rounds to seat the base plate and register the weapon.

(d) Fire-mission Tasks. In addition to the round count data, instrumentation will be required to estimate the impact point of each round fired during the fire for effect (FFE) task. Adjustment rounds need not be measured since the FO and FDC functions will be handled administratively. The crew will be issued firing instructions initially and canned messages will be used for adjusting. The final FFE command will be preceded by a set of instructions which will, if the mortar is properly oriented, place the FFE impact in the appropriate sector of the impact area. The mortar crew will then be ordered to switch to a new target, fire adjustment rounds, and finally an FFE mission.

The data required include time each round is fired as measured by the round count system and point of impact of each round as of the FFE as measured by observers using a triangulation technique. After each FFE or each fire-mission task an administrative halt will be required to mark each impact point for sighting purposes. The azimuth data are fed into the computer to determine impact point. Azimuths may be read directly from the sighting device (BC scope, theodolite) and transmitted to the computer over land line or radio for recording. Served controlled readout devices could be employed to read azimuth data directly into the computer. Time I events may be measured from film or video tape, or by an event recording system. The event system would consist of a simple set of switches which are wired directly into the ADP's. Manipulation of the switch causes the computer to determine the exact time and to record the event automatically. A series of switches, each for a different event, may be used by the observer(s).

Each crew will be given instructions to fire at three targets before moving to alternate locations. The data from each location are identical. The crew/task cycle will be repeated once for each of the four firing positions and a fifth time at reduced strength.

(5) Night Testing. The sequence referred to above and described in detail in Appendix III should be repeated at night to evaluate mortar performance under limited visibility conditions. The video recording instrumentation must have a night recording capability to insure that all necessary data are collected. Measurement of impact points may require marking of impact locations with a visible light source or measured after daylight to gather required data. Administrative breaks, which tend to interrupt the flow of the problem, may be required to allow sufficient time for data collection. A single firing position is used for night firings. The analysis is described in detail in Appendix III.

(6) Future Improvements for Mortar Testing. The major weakness in the current test procedures is in the use of canned messages which result in failure to require the crew to adjust the weapon system after each adjustment round. Much more attention must be paid to base plate orientation to insure that excessive slippage has not occurred which could require repositioning. The final FFE is apt to be less accurate than if the crew had precise information on which to base adjustments. It is unlikely that small differences in accuracy could be found by using canned messages.

The alternate system proposal is to develop an impact location system which automatically feeds the ADPS. As each adjustment round is fired, reliable data are fed into the computer from which the impact point can be calculated in near real time. The automatic system removes possible errors that could be introduced by an FO who makes an error in estimating the offset of the round from the target, or who fails to get a bracket on the subsequent round. The crew receives instructions from the computer as shown in

Figure 14 and continues to fire adjustment rounds until established criteria are met. The computer then issues the instructions for FFE and calculates the resulting rectangle of dispersion. Figure 15 shows a concept of the range configuration. Possible sensing techniques include seismic, optics, or acoustic. Current investigations have failed to locate such an automated system in current use. This could be a subject for failure study.

In this paragraph the advantages and disadvantages of the new system are compared to the system now within the Infantry Board capability. The new system provides:

(a) Improved resolution in rectangle of dispersion measurement.

(b) Improved resolution in offset error measurement.

(c) Permits more realism by removing all administrative halts to collect data.

(d) More realistic evaluation of mortar performance by including functions of FO and FDC without introducing any errors from these sources.

(e) Removing possibility of errors from such sources as poor alignment of triangulation devices, reading the devices, writing, or transmitting the data, and punching the data into the computer.

(f) Testing of the ammunition component (except possibly airburst) of the system more accurately because of better information on where the projectile actually landed and better data on where the projectile should have landed.

The disadvantages include infrequency of motor testing, cost of development, procurement, installation, and maintenance. However, these costs are partially offset by the fact that much of the instrumentation is already on hand. Only the sensor/signal conditioning/data link components are missing. Recommended signal conditioning and electronic filtering for both acoustic and seismic sensors appears in Appendix V.

(7) Constraints. This paper has primarily addressed field firing performance. This paper was not intended to span the entire spectrum of an expanded service test. The intention is to incorporate the procedures outlined in this paper into the field firing portion of the expanded service test.

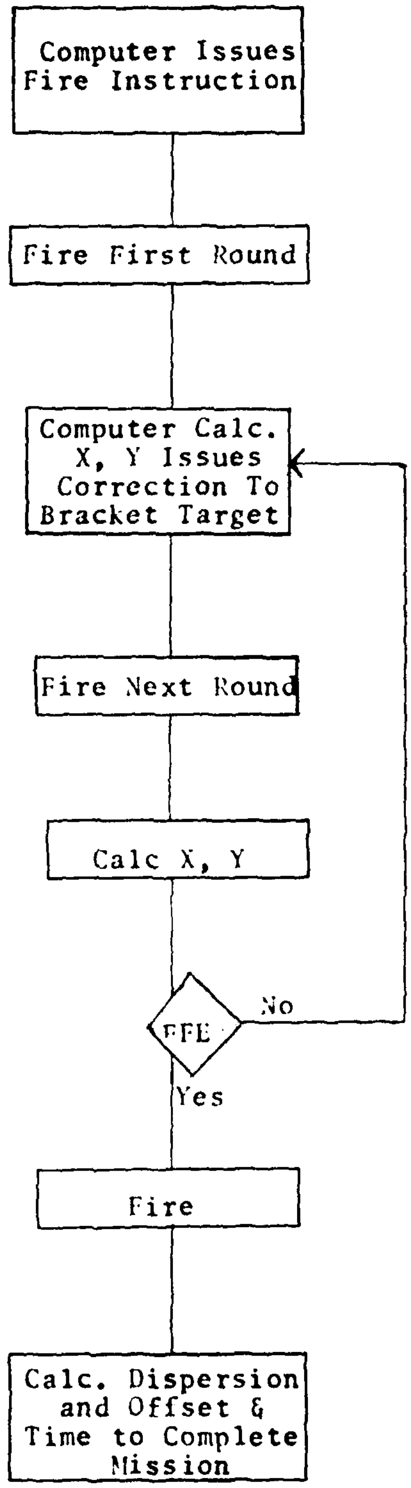
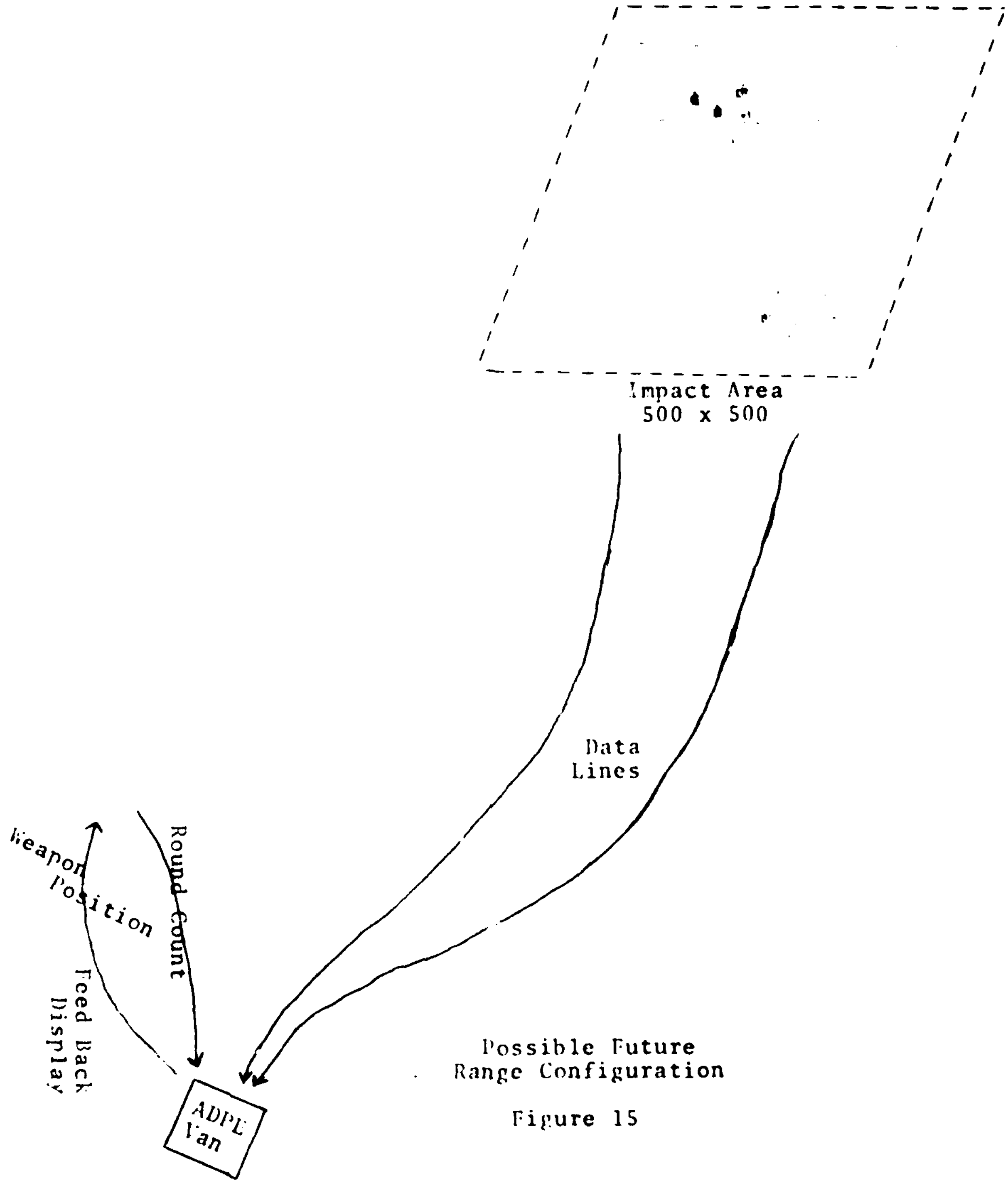


Figure 14 Automated Fire Control Technique



Possible Future
Range Configuration

Figure 15

VOLUME V

APPENDIX I

INFANTRY INDIRECT FIRE WEAPONS
METHODOLOGY REVIEW

INFANTRY WEAPONS TEST METHODOLOGY STUDY

INFANTRY INDIRECT FIRE WEAPONS METHODOLOGY REVIEW

D R A F T

JUNE 1972

UNITED STATES ARMY INFANTRY BOARD
Fort Benning, Georgia 31905

ABSTRACT

The Infantry Weapons Methodology Review (Indirect Fire). The initial approach taken was to identify all the types of combat actions that Infantry units encounter and analyze them to ascertain the critical tasks normally accomplished by the mortar crew when executing these combat actions. A comparison of these combat actions and critical tasks with the categories of effectiveness (accuracy, responsiveness, reliability, transportability, signature effects, and durability) validated the identification of measures of effectiveness (MOE). These MOE had been used in past testing and expanded by those compiled by the Infantry Weapons Test Methodology Study, a 5-year contractor supported effort to develop new measures and techniques of measuring the performance of competing Infantry rifles, indirect fire weapons, and antitank weapons. The MOE provide the discriminators between candidate weapon systems and can be measured in a simulated combat situation. In addition, the review examined the combat conditions to determine the type of facilities that would be required to gather the requisite MOE.

LIST OF ANNEXES AND APPENDICES

DEPARTMENT OF THE ARMY
UNITED STATES ARMY INFANTRY BOARD
Fort Benning, Georgia 31905

STEBC-MO-M

INFANTRY INDIRECT FIRE WEAPONS METHODOLOGY REVIEW

1. Problem. To validate, through the consideration of Infantry combat actions and the resulting combat tasks, measures of effectiveness and the tactical environments in which to obtain them that will permit discriminations to be made between competing indirect fire systems.

2. Assumptions.

a. Weapons tested on the instrumented range(s) will fire standard and developmental projectiles and fuzes.

b. Current doctrine concerning the mission, employment, and role of the mortar and crew in combat will not materially change in the near future.

c. Mortar systems will continue to be ground-mounted, vehicular mounted, or capable of both.

3. Facts Bearing on the Problem.

a. The service tests conducted by the Infantry Board are to be performed under simulated combat conditions as per AR 70-10.

b. The Infantry has three mortar systems (60-mm, 81-mm, and 4.2") that can be made available for use as control items.

c. The Infantry Board test methodology review is to establish test procedures and techniques that will insure the selection of the most effective weapons and equipment for the Infantry soldier. The approach taken to achieve this aim was to introduce these procedures into a simulated combat environment in which the candidate weapon and equipment will be required to function.

d. Prior to any review of Infantry indirect-fire weapons it must be established that the Infantry mortar is not a small artillery piece but a muzzle-loading, high-angle-of-fire weapon capable of a high degree of accuracy; further, the mortar has its special characteristics, such as trajectory, type of fire, service of the piece, crew functioning and tactical considerations.

4. Discussion.

a. This review concentrates on the weapons systems/crew interrelationship. To provide testing in a simulated combat environment, forward observer and fire direction techniques must be incorporated. This is foreseen by utilizing pre-planned fire commands to minimize human error.

b. The mortar crew must perform numerous drills in order to become proficient in hitting the target (accuracy). To eliminate the factor of proficiency is not a measurable factor and is therefore standardized by using the same crew for competing systems to eliminate the influence of human factors.

c. After research of all pertinent doctrinal and training literature, a list of the various combat actions normally accomplished by Infantry combat units supported by mortar fire was prepared. As a result of this research, 27 separate combat actions were identified and listed in Annex A. By the process described in Annex B, these 27 combat actions were reduced to the 10 most critical actions.

d. There are four critical crew tasks which must be considered in placing these indirect fire weapons into operation. However, the fourth category, transportation, can be included into the pre and post mission tasks; thereby eliminating the fourth category. The critical crew task cycle is shown at Annex C.

e. A list of the various indirect fire weapons combat tasks were formulated from pertinent doctrinal and training literature. These combat tasks must be performed by the mortar crew in support of combat actions. These tasks are listed in Annex D.

f. Further analysis of combat actions and combat tasks revealed certain interactions as shown by the matrix in Annex E. This demonstrates that all combat tasks are contained in the 10 critical combat actions thereby permitting the reduction of combat actions.

g. As a result of the study of combat actions and combat tasks certain measures for discriminating between competing mortar systems were validated. These are known as measures of effectiveness (MOE) and are discussed in detail in Annex F. The various MOE in the critical crew task cycle were grouped into categories of effectiveness measurable at the mortar site (responsiveness, reliability, signature effects, and durability); in the target area (accuracy); and during displacement (transportability). In each combat action the crew cycle is the same and all MOE are always gathered. No relative weighted values of the MOE can be assigned at this time.

h. A combat tasks/measures of effectiveness concept table is listed at Annex G.

i. A proposed indirect fire range configuration should have varied terrain and vegetation. Sites must have suitable terrain features to establish defense position, attack objectives, and a retrograde and advance-to-contact trail or road network. Annex H depicts a suitable range for the conduct of the combat actions necessary for collecting all the MOE.

5. Conclusions.

a. The MOE stated in this study will provide discriminators between competing weapons systems in a combat environment.

b. No weighted values can be assigned at this time.

c. The critical crew task cycle is performed in support of all combat actions accomplished by the Infantry.

d. The crew tasks and the weapon system capabilities required in support of the 27 Infantry unit combat actions overlap to the degree that these combat actions can be reduced to 10 critical combat actions.

6. Actions Recommended.

a. Investigation should be continued to determine the optimum means of collecting the MOE within the demands of the QMR.

b. Note should be made of the MOE which cannot be collected.

c. Investigation should continue to determine and assign weighted values to the various MOE.

ANNEX A

COMBAT ACTIONS OF INFANTRY COMBAT UNITS

1. Combat Outpost
2. Delaying Action
3. Roadblocks
4. Retrograde Operations
5. Deliberate Defense
6. Hasty Defense
7. Counterattack
8. Area or Position Security
9. Fire and Maneuver
10. Fire and Movement
11. Frontal Attack
12. Consolidation
13. Exploitation
14. Breeching Operations
15. River Crossing
16. Advance to Contact
17. Security of Moving Column
18. Combat in Cities
19. Search and Clear
20. Combat Patrol
21. Collapsing Defense and Withdrawal from an LZ
22. Sniper Team Support
23. Aerial Assault
24. Ambush
25. Close Combat
26. Recon Patrol
27. Counterambush

This is the list of infantry combat actions initially considered.

APPENDIX I TO ANNEX A

GROUPING OF COMBAT ACTIONS

Combat Outpost Roadblock Area/Position Security Hasty Defense Deliberate Defense Consolidation	Defense
Delaying Action Retrograde Operations Collapsing Defense and Withdrawal from an LZ	Retrograde Operations
Aerial Assault Combat in Cities Search and Clear Frontal Attack Ambush Fire and Maneuver Fire and Movement Sniper Team Support Counterattack Counterambush Close Combat Breaching Operations River Crossing	Attack
Advance to Contact Security of Moving Column Combat Patrol Exploitation Recon Patrol	Advance to Contact

Study of the 27 combat actions permitted grouping into four main categories as shown above. Individual combat actions were further studied and reduced for reasons shown on the following page.

ANNEX B

GROUPING OF COMBAT ACTIONS

[illegible] Support	Eliminate-combat tasks same as deliberate de
[illegible]	Eliminate-combat tasks same as deliberate de
[illegible] Security	
[illegible] Defense	
[illegible] Defense	
Consolidation	Eliminate-combat tasks same as hasty defense
[illegible] Action	Eliminate-combat tasks same as retrograde op
Retrograde Operations	
Collapsing Defense and Withdrawal from an LZ	Eliminate-combat tasks same as retrograde operations
Aerial Assault	Eliminate-combat tasks same as frontal attack
Combat in Cities	
Search and Clear	Eliminate-combat tasks same as advance to contact
Frontal Attack	
Ambush	
Fire and Maneuver	Eliminate-combat tasks same as frontal attack
Fire and Movement	Eliminate-combat tasks same as frontal attack
[illegible] Support	Eliminate-combat tasks same as ambush
Counterattack	Eliminate-combat tasks same as frontal attack
Counterambush	Eliminate-indirect fire weapons seldom used
[illegible]	Eliminate-indirect fire weapons seldom used
[illegible] Operations	Eliminate-combat tasks same as frontal attack
River Crossing	
Advance to Contact	
Security of Moving Column	Eliminate-combat tasks same as advance t
[illegible] Patrol	Eliminate-combat actions same as ambush contac
Exploitation	
[illegible] Patrol	Eliminate-combat actions same as advance to contact

The above combat actions have been eliminated for the reasons shown. Combat tasks for each combat action were considered in detail and where close similarities existed between two combat actions the more important was chosen.

FINAL LIST OF COMBAT ACTIONS

Area/Position Security

Hasty Defense

Deliberate Defense

Retrograde Operations

Combat in Cities

Frontal Attack

Ambush

River Crossing

Advance to Contact

Exploitation

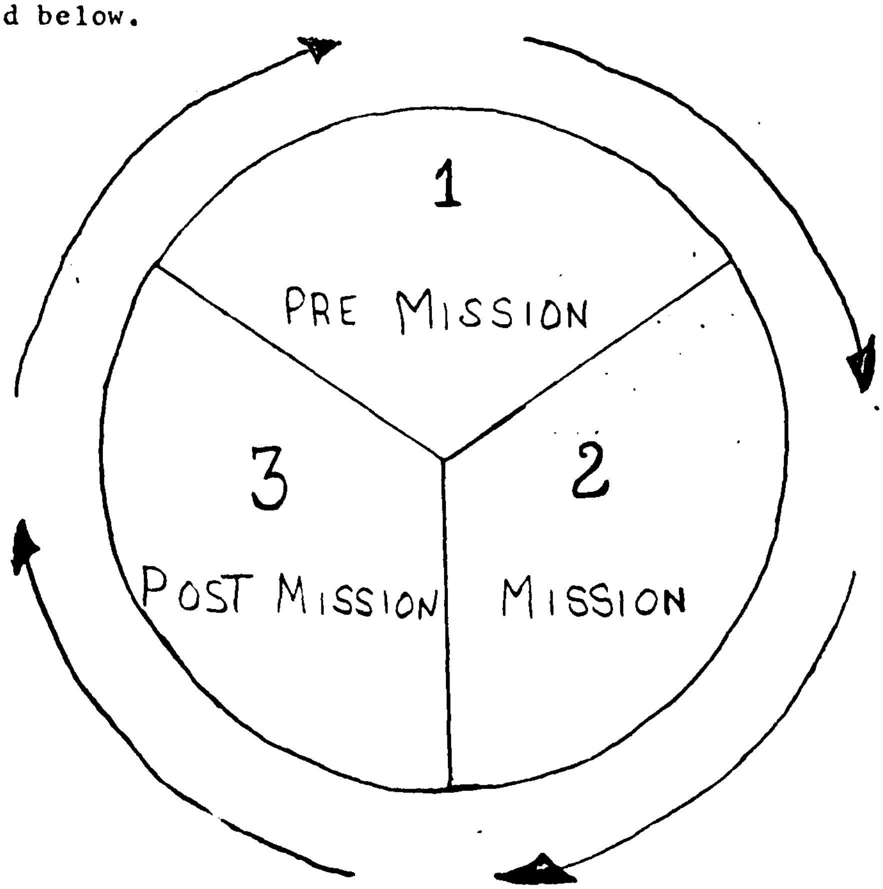
The above list of combat actions includes all tasks expected to be performed by an indirect fire crew in a combat environment.

ANNEX C

CRITICAL CREW-TASK CYCLE

1. PRE-MISSION TASKS
2. MISSION TASKS
3. POST-MISSION TASKS

As defined by the mortar manual, the critical crew-task cycle was divided into four categories. The fourth category is transportation tasks. Further study of this category indicated that it did not merit sufficient importance to be treated separately. Therefore, placing the mortar in action was included in pre-mission tasks while taking the mortar out of action and displacement was incorporated into post mission tasks. The continuous cycle is graphically depicted below.



PRE-MISSION TASKS

	FM 23-90 Para	FM 23-92 Para	FM 23-85 Para	Othe
a. Dismount Mortar	79	68	14-99	E-5
b. Place Mortar in Action	74	63	13,95 102,103	
c. Lay Mortar	82-83	71-72	79-84,87 90	
d. Sight Calibration	31	33	35-37	
e Prepare for Firing	121	69	58	
f. Prepare and Camouflage Position	105		Same as 81-mm	E-13, FM 7-20 4.2
g. Care and Cleaning	48	11	15-19-21 -29	

MISSION TASKS

	FM23-90 Para	FM23-92 Para	FM23-85 Para	Other
a. Firing the Mortar	85	74	97,98	
(1) Settle Base Plate	88	63	97	
(2) Registration	122-123-124	138-139 142-143	181	
(3) Adjust Sheaf	124-125 126	141-142	186	
(4) Fire Mission Control	118	106,107	169	
b. Prepare Ammunition and Fuzes	13-14-15	18	58-64	
c. Prepare and Camouflage Position	105		Same as 81-mm	E-13 FM 7-20 4.2
d. Care and Cleaning	49	11	15-19, 21-29	

POST-MISSION TASKS

	FM 23-90 Para	FM 23-92 Para	FM 23-85 Para	Other
a. Relaying After Firing	62	53	Same as 81-mm	
(1) Defense	108		Same as 81-mm	118 FM 7-1 81-mm
(2) Offense	107	131	Same as 81-mm	
(3) Preparation of Ammo and Fuzes	17	16,17 20	58-64	
b. Inspection of Equipment			30	
c. Care and Cleaning	50	12	15-29	
d. Preparation and Camouflage Position	105			E-13 FM 7-2(
e. Resupply		133	128	E-16 FM 7-2(4.2, 252,25(FM 7-1: 81-mm
f. Mortar Out of Action				
g. Displacement	109			FM 7-2(4.2

ANNEX D

COMBAT TASKS OF INFANTRY INDIRECT FIRE WEAPONS

1. Preparation of site
2. Mounting the mortar
3. Prefire safety checks
4. Sight calibrations
5. Laying the mortar
6. Placing out aiming posts
7. Prepare ammo & fuses
8. Relaying after fire
9. Registration
10. Adjusting the sheaf
11. Refer the sight
12. Large deflection shifts
13. Traversing fire
14. Searching fire
15. Rapid fire
16. Sustained fire
17. Night firing
18. Remove misfires
19. Dismount mortar
20. Displacement
21. Care & cleaning
22. Ammo resupply

ANNEX E

TASK/ACTION CONCEPT TABLE	Area Position Security	Hasty Defense	Deliberate Defense	Retrograde Operations	Combat in Cities	Frontal Attack	Ambush	River Crossing	Advance to Contact	Exploitation
Preparation of Site	X	X/	X	X	X	X	X	X	X	X/
Mounting the Mortar	X	X	X	X	X	X	X	X	X	X
Prefire Safety Checks	X	X	X	X	X	X	X	X	X	X
Sight Calibrations	X	X/	X	X	X	X	X	X	X	X
Laying the Mortar	X	X	X	X	X	X	X	X	X	X
Placing Out Aiming Posts	X	X/	X	X	X	X	X/	X/	X	X/
Prepare Ammo & Fuses	X	X	X	X	X	X	X	X		X
Relaying After Fire	X		X	X	X	X				
Registration	X		X	X	X	X				
Adjusting the Sheaf	X		X	X	X	X				
Refer the Sight	X		X	X	X	X				
Large Deflection Shifts	X	X	X	X	X	X	X	X	X	X
Traversing Fire	X	X	X	X	X	X	X	X	X	X
Searching Fire	X	X	X	X	X	X	X	X	X	X
Rapid Fire	X	X	X	X	X	X	X	X	X	X
Sustained Fire	X		X	X	X	X				
Night Fire	X	X	X	X	X	X	X	X	X	X
Remove Misfires	X	X	X	X	X	X	X	X	X	X
Dismount Mortar	X	X		X	X	X	X	X	X	X
Displacement	X	X		X	X	X	X	X	X	X
Care and Cleaning	X	X	X	X	X	X	X	X	X	X
Ammo Resupply	X		X	X	X	X			X	X

Symbol X/ indicates that task may be performed during that combat action depending on the situation.

ANNEX F

MEASURES OF EFFECTIVENESS FROM INFANTRY INDIRECT-FIRE WEAPONS METHODOLOGY STUDY

CATEGORIES OF EFFECTIVENESS	MEASURES OF EFFECTIVENESS
ACCURACY	NUMBER OF HITS
	RECTANGLE OF DISPERSION
	ROUND DISTRIBUTION
	NUMBER OF ROUNDS FOR ADJUSTMENT
RESPONSIVENESS	TIME TO PLACE MORTAR INTO ACTION
	TIME TO REGISTER
	TIME TO FIRST ROUND
	TIME TO TARGET HIT
	TIME TO RELAY
	TIME TO SHIFT FIRES
	TIME TO RELAY (LARGE DEFLECTIONS
	TIME TO PLACE MORTAR OUT OF ACTION
	TIME TO PREPARE AMMUNITION
RELIABILITY	NUMBER OF ROUNDS BETWEEN MALFUNCTIONS
	FREQUENCY OF SIMILAR MALFUNCTIONS
	TIME TO CLEAR MALFUNCTIONS
	NUMBER OF ROUNDS BETWEEN CLEANINGS
TRANSPORTABILITY	MOVEMENT TIMES (VEHICULAR)
	EASE OF PORTABILITY (FOOT)
SIGNATURE	SOUND LEVEL RECORDING (BLAST)
	OBSCURATION (SMOKE AND HAZE)
	VISUAL LIGHT EMISSION (FLASH)
DURABILITY	WEAROUT FAILURES

DISCUSSION OF MEASURES OF EFFECTIVENESS

1. General. Consideration of the seven categories of effectiveness revealed that these categories must be further defined in terms of measureable parameters which meaningfully relate to a combat situation. These parameters were examined in detail and denoted as measures of effectiveness (MOE). These MOE thereby permit proper evaluation of small differences between competing weapons systems.

2. The measures of effectiveness are discussed below under each category of effectiveness.

a. Accuracy. Four measures considered in the category of accuracy are number of hits, rectangle of dispersion, round distribution, and number of rounds for adjustment.

(1) Number of Hits. A round impacting in a circle with a point target as the center and a radius that equals the radius of the lethal area of the round is defined as a hit. Hits are described as a percentage (number of hits divided by total rounds fired). This MOE permits evaluation of the consistency of a weapons system to place effective fire.

(2) Rectangle of Dispersion. This MOE provides a statistical analysis of dispersion characteristics for competing weapons systems. The standard deviation is computed for both range and deflection. The size of one rectangle of dispersion is one range standard deviation (RSD)

long and one deflection standard deviation (DSD) wide. This rectangle contains a theoretical 46% of all impacting rounds. A double rectangle of dispersion is two RSD long, two DSD wide, and contains a theoretical 91% of all impacting rounds. Comparison of rectangles of dispersion demonstrates relative tightness of dispersion of competing weapons systems.

(3) Round Distribution. The pattern of impacting rounds lends itself to a statistical analysis for such parameters as center of impact, maximum spread (range and deflection), mean radius, and offset. Although these parameters cannot conclude the worth of two competing systems with respect to accuracy, they are indicators of accuracy.

(4) Number of Rounds for Adjustment. The ability of one weapons system to place effective fire on a target with fewer adjusting rounds than another weapons system demonstrates a distinct advantage. The fewer rounds the weapons requires to attain accurate fire the more desirable the system becomes.

b. <u>Responsiveness</u>. There are nine measures considered in this category.

(1) Time to place the mortar in action. The time from when the mortar position has been identified until the mortar is set and ready for registration is the measureable factor. Crew drill, the actions required of the crew to

set up the weapon and make ready to fire (this includes compatibility with the aiming circle, compass, and all ancillary equipment), determines how long this measure takes. Requirements vary from weapons system to weapons system and the simplest, least time-consuming is most desirable.

(2) Time to Register. The measurable factor is identified as the time from when the first round is placed in the tube until the mortar is registered. This MOE is a function of settling the base plate, sight manipulation, and adjustment of elevation and deflection mechanisms. Significant differences could be found in this area between competing systems.

(3) Time to First Round. This measure provides data on the length of time it takes the crew from "fire mission alert" to fire the first round. This MOE includes small deflection and elevation changes. It does not include preparation of the ammunition.

(4) Time to Target Hit. This measure is defined as the time elapsed from first round fired until a target hit is accomplished. It includes small elevation and deflection changes.

(5) Time to Relay. This measure is defined as that time to relay the mortar on base stake from end of fire mission.

(6) Time to Shift Fires. When the gunner cannot lay the mortar for deflection using the traversing mechanism, he must move the bipod assembly. A shift is defined as a move that includes picking up the bipod/standard and bridge, minus the base plate on current weapons, and rotating it to a new location along a 6400 mil circle. The time from the command "fire mission" until the first round is placed in the tube is the measurable factor. Small deflection changes are included in time to first round MOE.

(7) Time to Relay the Mortar (Large Deflection Changes). This measure is defined as that time to relay the mortar on base stake from "end of fire Mission". This is a function of moving the bipod assembly.

(8) Time to Place Mortar Out of Action. This is defined as the time from the command "out of action" until the mortar is ready to move. This is a function of weight, configuration, and component interface.

(9) Time to Prepare Ammunition. This is defined as the time when the round is removed from the shipping carton and prepared for firing. This is a function of weight, fuzes, and special handling requirements.

c. Reliability. There are four measures considered in the category of reliability.

(1) Number of Rounds Between Malfunctions. One weapons system and its ammunition may have more malfunctions than another as a result of system or ammunition design. The number of rounds fired between malfunctions determines the probability of successfully accomplishing a mission. This MOE is given a great deal of consideration when determining overall suitability.

(2) Frequency of Malfunctions. The number of occurrences of one malfunction is an indicator of component deficiency. This MOE is important in identifying problems and recommending corrections. Repetition of a single malfunction will not usually cause the system to be qualified unsuitable unless the deficiency is not correctable.

(3) Time to Clear Malfunctions. This is defined as the time from when the malfunction has been realized until it has been corrected and the first round placed in the tube. The ability to correct a malfunction in the minimum amount of time is critical factor and bears more than average weight when making a suitability recommendation.

(4) Number of Rounds Between Cleanings. The number of times a weapons system has to be cleaned and the ease of cleaning are important indicators of combat effectiveness. A system that requires less cleaning than another is more desirable.

d. Transportability. There are two MOE considered in this category.

(1) Transportability (Vehicular mode). This measurement evaluates speed of movement with the weapon in various combat situations. The parameters that must be standardized for competing weapons systems are terrain, weather, and the mode of transportation. The time begins when the mortar is out of action and ready to move at point A and terminates at point B when the mortar has been dismounted and is ready to put in action.

(2) Ease of Portability (Foot). Consideration must be given to maneuverability in particular when being moved by foot. Varied types of representative terrain should be used that include common obstacles such as streams, luxuriant vegetation, and swamp areas. This MOE permits a valid evaluation of the mortar/crew interface. The overall configuration of one system may permit greater ease of portability than with another system.

e. Signature Effects. There are three measures considered in this category.

(1) Sound Level Recording (Blast). This signature effect will be measured and evaluated in three parameters: (a) to determine if there is any danger to the crew, (b) to determine if the sound of the weapon will readily identify

its location on the battlefield, and (c) to determine if the sound is peculiar to the weapon which would readily classify it on the battlefield.

(2) Obscuration (Smoke and Haze). This signature effect will be measured and evaluated in two parameters: (a) to determine if the muzzle blast causes sufficient physical contaminants (smoke, dust, dirt) to interfere with crew drill operations, and (b) to determine if these contaminants will disclose the crew/weapon position.

(3) Visual Light Emission (Flash). This signature effect will be measured in such terms as size, duration, and intensity during day and night conditions.

f. Durability. The measure considered in the category of durability is Service Life (i.e. component wear). The wear caused by transportation, terrain, weather, assembly and disassembly, and firing of the weapon are the measurable factors. Durability takes into consideration the factor of stability which is the ability of a weapons system to consistently maintain its fire mission posture. Reliability and durability differ in that reliability accounts for instantaneous failures whereas durability is a function of wearout failures.

COMBAT TASKS CONCEPT TABLE

COMBAT TASKS / MEASURES OF EFFECTIVENESS	Number of Hits	Rectangle of Dispersion	Round Distribution	Number of Rounds For Adjustment	Time to Place Mortar in Action	Time to Regist…	…e to Firs…	Ti…
Preparation of Site					X			
Mounting the Mortar					X			
Prefire Safety Checks					X			
Sight Calibrations					X			
Laying the Mortar					X			
Placing Out Aiming Post					X			
Prepare Ammo & Fuses					X			
Relaying After Fire								
Registration	X	X	X	X		X	X	X
Adjusting the Sheaf	X	X	X	X				
Refer the Sight								
Large Deflection Shifts			X	X				
Traversing Fire	X		X	X			X	X
Searching Fire	X		X	X			X	X
Rapid Fire	X	X	X				X	X
Sustained Fire	X	X	X				X	X
Night Fire	X	X	X	X			X	X
Remove Misfires								
Dismount Mortar								
Displacement								
Care and Cleaning								
Ammo Resupply								

... Target Hit	Tire to Relay	Time to Shift Fires (Large Deflection)	Time to Relay (Large Deflection)	Time to Place Mortar out of A...	Time to Prepare Ammunition	Number of Rounds Between Malfunctions	Frequency of Similar Malfunctions	Time to Clear Malfunctions	Number of Rounds Between Cleanings	Movement Times (Vehicular)	Ease of Portability (Foot)	Sound Level	...cordin...
					X								
	X												X
												X	X
												X	X
	X												
		X	X										
	X					X	X		X			X	X
	X					X	X		X			X	X
	X					X	X		X			X	X
	X					X	X		X			X	X
	X					X	X		X			X	X
								X					
				X						X	X		
				X						X	X		
					X								

celeration	Visual Light Emission	Wearout Failures
		X
		X
		X
		X
		X
		X
	X	X
		X
		X
	X	X
	X	X
	X	X
	X	X
	X	X
		X
		X
		X
		X

ANNEX H

PROPOSED INDIRECT-FIRE FACILITY

1. General Tests of candidate indirect-fire weapons systems must be conducted on a reliable instrumented facility which will provide realistic comparison.

a. Sufficient terrain on which to maneuver the platoon tactical unit to which the candidate weapons are normally assigned.

b. The ranges and safety fans necessary to test the maximum, maximum effective, and minimum ranges of the candidate weapons.

c. Terrain to provide a defensive area and attack area for primary, alternate, and supplementary firing positions.

d. Terrain to provide a road for advance to contact and retrograde operations. This road must have at least two firing positions.

2. Discussion.

a. The facility and terrain shown in Appendix 1 does not represent any particular piece of terrain but is merely a sketch of what a suitable indirect-fire facility should look like.

(1) The range is designed to test the following combat actions

(a) Deliberate Defense

(b) Hasty Defense

(c) Area Position Security

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(d) Retrograde Operations

(e) Frontal Attack

(f) Ambush

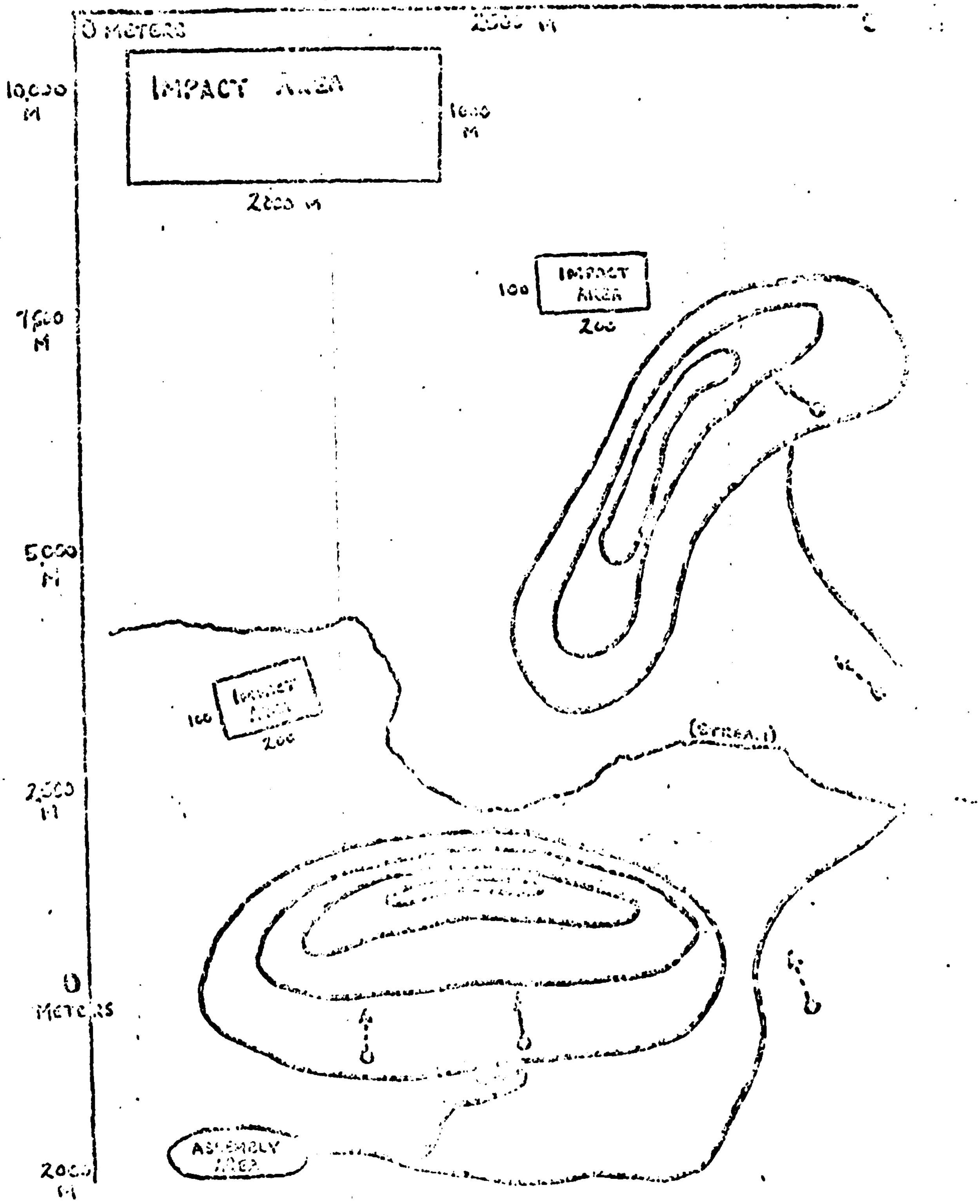
(g) Advance to Contact

The combat actions tested on the range comprise 7 of the 10 critical combat actions selected by this study to represent the remaining 27 combat actions. The three remaining critical combat actions must be tested on separate facilities which includes environmental conditions peculiar to each action. Combat in cities requires the use of the built up area. River crossing should include enough water to require the use of water borne craft. The exploitation is in effect a cross country exercise requiring for more terrain that can be incorporated in the basic facility.

b. Crew training will be required upon receipt of candidate weapons. Range facilities for this training are considered to be locally available.

c. The proposed facility (Figure 1) contains three major impact areas. It contains not only enough range to fire maximum charge of all standard mortar systems, but it also allows for future developments which will increase range. Targets have not been discussed since a separate study is required to determine type and location of representative targets.

FIGURE [illegible] H



0 METERS
10,000 M
IMPACT AREA
1000 M
2000 M
100
IMPACT AREA
200
7500 M
5000 M
100
IMPACT AREA
200
(STREAM)
2500 M
0 METERS
ASSEMBLY AREA
2000 M

ANNEX I

REFERENCES

ARMY SUBJECT SCHEDULES

7-1	Organization, Mission, Capabilities and characteristics of the Infantry, Mechanized Infantry and Airborne Battalions
7-7	81-mm Mortar Squad Tactical Training
7-9	Patrolling
7-11C10	Changes 1 and 2, MOS Technical Training and Refresher Training of Infantry Indirect Fire Crewman
7-12	Antiinfiltration and Counterguerrilla Training
7-27	Heavy Mortar Platoon Tactical Training
7-31	Weapons Platoon Tactical Exercise
7-40	Rifle Company Tactical Exercise
7-53	Drop Zone Assembly
17-37	Rifle Squad, Armored Car or Reconnaissance Platoon
21-16	Antiinfiltration and Guerrilla Warfare Training

ARMY TRAINING PROGRAMS

7-4	Change 1, Infantry, Airborne and Mechanized Division, HHC
7-4-1	Infantry, Airborne and Mechanized Division
7-15	Infantry, Airborne Infantry, Airmobile Infantry, Light Infantry and Mechanized Infantry Battalions and Brigades
7-16	Change 1, HHC, Infantry, Airborne Infantry, and Mechanized Infantry Battalions

7-16-1	Change 1, HHC, Infantry, Airborne Infantry, and Mechanized Infantry Battalions
7-18	Rifle Company, Infantry, Airborne, Airmobile and Light Infantry Battalions
7-18-1	Rifle Company, Infantry, Airborne, and Mechanized Infantry Battalions
7-42	HHC, Infantry, Airborne, and Mechanized Brigades
7-42-1	Change 1, HHC, Infantry, Airborne Infantry, Airmobile Infantry, and Mechanized Infantry Brigades
7-47	Rifle Company, Mechanized Infantry Battalion
7-52	HHC, Infantry Brigade, Separate
7-56	HHC, Airmobile and Light Infantry Battalions
7-157	Infantry Long Range Patrol Company

ARMY TRAINING TESTS

7-15	Infantry Battalions
7-16-1	Heavy Mortar Platoon, HHC, Infantry, Airborne Infantry, and Mechanized Infantry Battalions
7-18	Change 1, Rifle Company, Infantry and Light Infantry Battalions
7-35	Airborne Infantry Battalions
7-37	Rifle Company, Airborne Infantry Battalions
7-45	Mechanized Infantry Battalion
7-47	Rifle Company, Mechanized Infantry Battalion
7-55	Airmobile Infantry Battalion
7-157	Infantry Long Range Patrol Company

FIELD MANUALS

7-11	Change 1, Rifle Company, Infantry, Airborne and Mechanized
7-15	Change 1, Rifle Platoon and Squads, Infantry, Airborne and Mechanized
7-20	Infantry, Airborne Infantry, and Mechanized Infantry Battalions
7-30	The Infantry Brigades
17-36	Division Armored and Air Cavalry Units
21-50	Ranger Training and Ranger Operations
21-75	Combat Training of the Individual Soldier and patrolling
23-85	60-mm Mortar, M19
23-90	Change 1, 81-mm Mortar, M29
23-92	Changes 1-4, 4.2-inch Mortar, M30
31-10	Denial Operations and Barriers
31-16	Counterguerrilla Operations
31-18	Change 1, LRR Ranger Company
31-21	Special Forces Operations--USA Doctrine
31-23	Stability Operations, USA Doctrine
31-25	Desert Operations
31-30	Jungle Training and Operations
31-36	Night Operations
31-50	Change 1, Combat in Fortified and Built-up Areas
31-55	Border Security/Antiinfiltration Operations
31-60	River Crossing Operations

31-70	Basic Cold Weather Manual
31-71	Change 1, Northern Operations
31-72	Mountain Operations
31-73	Advisor Handbook for Stability Operations
31-75	Riverine Operations
57-1	US Army/US Air Force Doctrine for Airborne Operations (AFM 2-51)
57-35	Airmobile Operations

TRAINING CIRCULARS

23-12	Change 1, Target Detection--Crack and Thump Technique
23-13	Crew Served Weapon Night Vision Sight

VOLUME V

APPENDIX II

PROJECT ANALYSIS

INDIRECT FIRE FACILITY

PROJECT ANALYSIS

INDIRECT FIRE FACILITY

Prepared by Mellonics Division, Litton Systems Inc., under Contract DAEA18-68-C-0004

September 12, 1969

TABLE OF CONTENTS

1. INTRODUCTION AND SUMMARY

This project analysis has been performed under Contract DA EA18-68-C-0004 in connection with the Infantry Weapons Test Methodology Study conducted under USAIB auspices at Fort Benning, Georgia. The analysis covers the design, development, and use of an instrumented range for testing indirect fire weapons in a quasi-combat environment.

The indirect fire range will yield quantitative data for use in weapon evaluation under operational conditions. The range will also permit controlled observation of testing and variation of test conditions to augment the quantitative findings with data related to the subjective aspects of weapon system evaluation, with special emphasis on human factors. These features will further permit comparative testing of two or more candidate weapons systems.

The purpose of this analysis is to furnish guidelines in the development of an indirect fire range, to establish basic test concepts, to make a preliminary determination of instrumentation and data collection requirements, and to present a PERT summary of the tasks to be performed in range development.

2. OBJECTIVES

The objectives in establishing the Indirect Fire Facility will be:

(1) To develop and evaluate methodologies for testing indirect fire weapons in the field under quasi-combat conditions.

(2) To identify those factors which are critical to the evaluation of infantry weapons in such an environment.

(3) To obtain field test data as a basis for establishing measures of system effectiveness.

(4) To develop objective standards for comparing system effectiveness.

. ANALYSIS OF CRITICAL FACTORS

Critical factors affecting the capability of the Indirect Fire Facility to achieve its stated objectives fall into three general categories:

(1) Factors related to materiel
(2) Factors related to personnel
(3) Factors related to test design and conduct.

a. Materiel

These factors fall into two sub-categories. Those which are not subject to assessment under field test conditions, and which could introduce bias or error in test results, will be controlled or held constant during field test. Such factors include the following:

(1) Inherent accuracy
(2) Operating procedures
(3) Field maintenance procedures

Assessment of other materiel-associated factors which will establish a figure of merit for the weapon system will be a primary objective of tests conducted on the Indirect Fire Facility. These factors include the following:

(1) Rate of fire
(2) Bias and dispersion
(3) Reliability
(4) Maintainability
(5) Ease of clearing malfunctions

b. Personnel

Factors related to personnel must be identified to avoid introduction of bias in test results. These factors include the following:

(1) Crew and forward observer proficiency

(2) Stress and fatigue
(3) Motivation
(4) Leadership

A variety of methods may be employed to reduce or eliminate bias, such as randomization and the use of preset commands. Stress and fatigue can be controlled to a certain extent, primarily through the application of demanding time constraints and information overload. The factor generally considered to be the most difficult to introduce - fear in combat - should be relatively unimportant in indirect fire testing, except for grenade testing conducted at close ranges. Annex B contains an extended discussion of these topics.

c. Test conduct

Test designs discussed in this document are based on the following weapons, whose characteristics are assumed to be comparable to weapons undergoing tests during the period 1969 - 1975:

(1) ~~Mortar, 60 mm, crew~~-served
(2) Mortar, 81 mm, crew-served 4.2
(3) 40 mm grenade launcher, M79
(4) 40 mm grenade launcher, XM148

To insure operationally meaningful test results, U.S. doctrine relating to mortar and grenade usage will be employed to the maximum extent feasible in a quasi-combat environment. Other departures from doctrine may be introduced by the imposition of test controls necessary to achieve valid test results and to isolate critical parameters. Doctrine relative to mortar operations is summarized in Annex D .

4. TEST VARIABLES

Variables to be considered in testing indirect fire weapons are listed below in three categories: independent, dependent, and random.

(1) Independent variables. These variables are subject to control, and will be established prior to testing:

- (a) Observer-target range
- (b) Target characteristics
- (c) Method of target location
- (d) Observer proficiency
- (e) Weapon type
- (f) Ammunition type
- (g) Crew proficiency
- (h) Sensor deployment
- (i) Visibility and target illumination

(2) Dependent variables.

- (a) Time to acquire target
- (b) Time to process fire request
- (c) Reported target location
- (d) Time to fire adjustment round
- (e) Rounds expended in adjustment fire

(3) Random variables. These variables are not controllable. Their effect on testing and the validity of test results can be minimized by careful selection of test conditions and replication under a variety of conditions.

- (a) Natural light
- (b) Vegetation and terrain
- (c) Weather
- (d) System malfunctions
- (e) Ballistics

Variables to be measured in conducting weapons tests on the indirect fire range will include the following:

(1) Point of Impact. The point of impact for each projectile will be determined by reducing seismic data obtained from a

geophone array.

(2) Response time. Several types of response time will be measured:

(a) Time to move crew and weapon from rendezvous area, set up weapon, and deliver first round

(b) Time to adjust weapon and deliver subsequent adjustment rounds under direction of forward observer or FDC

(c) Time elapsed between weapon emplacement and commencement of fire-for-effect. (This is closely related to the number of adjustment rounds required to achieve a given level of accuracy.)

(d) Time to shift fire from a registration point to a target (surprise fire mission).

(3) Round count as a function of time.

(4) Target acquisition errors. Correlation of actual impact points obtained from geophone data and apparent impact points derived from adjustment commands by the forward observer will allow objective measurement of observer error.

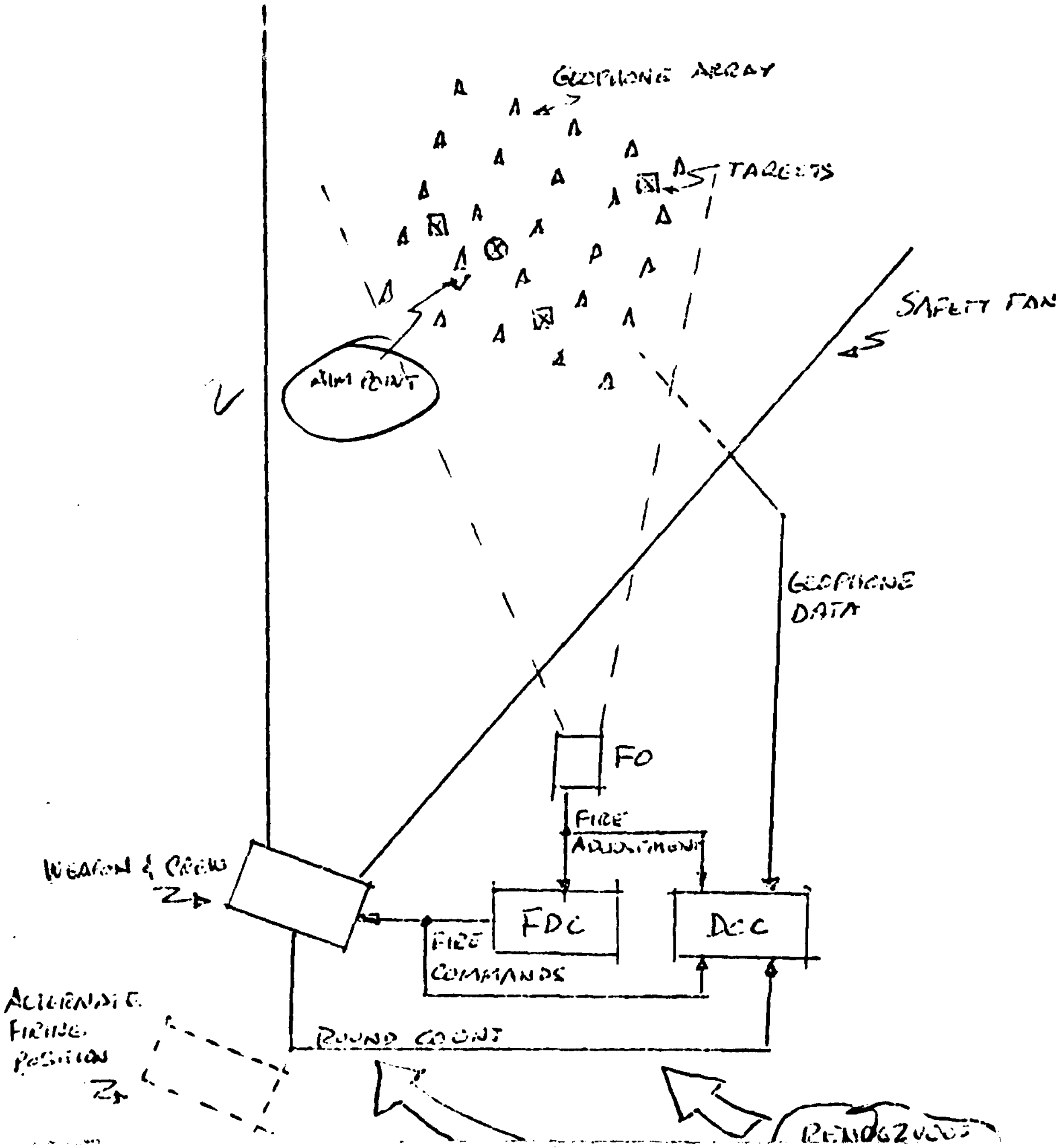
(5) Environmental factors. Wind velocity and direction, target visibility, terrain characteristics, and other factors affecting mission performance will be objectively measured or categorized (e.a., good, fair, poor).

(6) Rounds expended prior to fire for effect. This is a measure of efficiency in adjusting fire, and is influenced by crew and observer proficiency.

5. TEST CONCEPTS

a. Mortar gunnery tests

The basic mortar gunnery test configuration is shown schematically below:



The test begins with identification of the target by the forward observer (FO), who transmits a request for fire to the mortar crew located in the rendezvous area. The crew transports the weapons to the designated firing position. Simultaneously, the Fire Direction Center (FDC) Crew moves to the FDC. Upon emplacement of the mortar, the FDC processes the fire request from the FO and relays fire commands to the crew. An adjustment round is fired, and the FO notes its impact location relative to the target. This information is transmitted to the FDC, which computes adjustments in range and deflection to bracket the target with the next round. This procedure is repeated until the observed impact point is within a given radial distance of the target at which time fire for effect commences.

Geophone data is automatically relayed to the Data Collection Center (DCC) via land line, as is the round count. Communications between FO, FDC, and mortar crew are recorded at the DCC.

Two methods of fire correction will be employed: The Target Grid Method and the Photo Survey Method. A brief description of each will be given here. Detailed descriptions of these methods are given in FMC-40.

1. Target Grid Method. This technique is used in instances where the target can be seen by the FO, who observes deviations relative to an observer-target line of sight and relays this information to the FDC. The FDC converts these data into corrections in range and deflection relative to the weapon-target line and relays fire commands to the mortar crew.

2. Photo Survey Method. This technique can be used in instances where bursts cannot be seen by the FO (e.g., night operations, visual obstruction due to terrain and/or vegetation) or where fire for effect without adjustment is desired, as in the case of surprise attack. Briefly, the FO notes the target location on a gridded aerial photograph, and relays this data to the FDC, which plots the locations of the weapon and target on a similar photo. Firing commands are issued by the FDC and fire for effect commences without adjustment rounds. An alternate method of correction by photo survey employs one or more adjustment rounds fired at an observed aim point for registration purposes and subsequent fire on a target located relative to that aim point without further adjustment fire.

An analysis of impact area instrumentation is given in Annex C.

b. GRENADE LAUNCHER TESTS

Grenade launchers will be tested against point targets at ranges up to 150 yards and against area targets at ranges from 150 to 350 yards.

1. Point Targets

For point-fire testing, the target array will be similar to that used in the attack facility, with the exception that hardened targets must be used to prevent blast and shrapnel damage to the electronic equipment. With additional hardening, the attack facility could be used for grenade testing.

Near-miss sensing will be acoustic, with a signal threshhold set to trigger on detonation at distances less than or equal to the casualty radius of the grenade. Hit scoring will be derived from acoustic data supplemented by visual inspection of the target.

With the current emphasis on limited engagement and counterinsurgency operations, it may be desirable to test the weapons in a simulated urban environment. Targets in this instance would include doorways and windows at various elevations, alleys, cul-de-sacs and other features characteristic of built-up areas. The use of such a facility would establish the suitability of the weapon for use in severely confined environments requiring rapid response to unexpected stimuli, such as small arms simulators installed at strategic points in the target complex and triggered by concealed photocells along the line of advance.

2. <u>Area Targets</u>

At ranges in excess of 150 yards, firing will be at area targets. The indirect fire facility geophone array and associated data collection equipment will be used to determine impact point.

3. <u>Test Procedure</u>

The basic grenade launcher test procedure for point target fire will test the equipment under simulated assault conditions, with troops moving toward the target complex and firing from predetermined event lines. The test scenario will include firing from standing, kneeling and prone positions.

Small arms simulators will be associated with the targets to introduce visual cues and to enhance a realistic combat environment. One departure from combat doctrine will be present in grenade tests The grenadier will operate alone, rather than with the supporting elements of a rifle squad. Two reasons are advanced for this departure:

(1) Safety risks to test personnel will be minimized.
(2) It is not evident that the supporting personnel will affect the test results in a significant fashion.

Considerable analysis has been devoted to the fragmentation pattern and casualty radius associated with 40mm grenades. It may be desirable in some instances to fire dummy grenades and to deduce their effect by simulation of the fragmentation pattern.

6. INSTRUMENTATION

1. Point of Impact Measurement Systems.

a. Seismic System

(1) The principal range instrumentation will consist of a point of impact measurement system. The seismic system will consist of an array of seismometers buried to a depth that would prevent damage by a burst directly above. The "soil" layer varies in depth from 24 to 51.5 meters and is sufficient to protect the seismic devices. The array of seismometers will cover an area 300 meters in radius. Separation of seismometers will be at 125 meter intervals which is the approximate limit of detection of the "P" wave in the "soil" layer. Such an array will require approximately 30 seismometers. Figure 4, Annex C, shows a schematic diagram of such an array.

(2) Cables buried at a safe depth will be used to transmit the impulses generated by the seismometers to the computer. The first seismometer to sense a hit will provide an initial time. The second, third and possibly fourth seismometers to sense a hit will provide additional times from which the point of impact can be computed by a method of time differences.

(3) Distance resolution of the seismic system is estimated to be within 5 meters and is based on the capability of the first arrival being measured with an accuracy of .0025 seconds. Because the "P" wave in the "soil" layer propogates between 1.69 and 1.90 kilometer/second, the distance resolution is determined principally by the product of the time resolution (.0025 seconds) and the shock wave speed (1.90 km/sec)= 4.75 meters. Time differences observed among sensors is the distance between sensors divided by the velocity minus corrections required for differences in sensor elevation, soil velocity variations and dip in the interface.

b. Flash Base System. The artillery flash base system is capable of locating point of impact to the accuracy desired if sufficient observation points are used and if the flash base team has a knowledge of the general area in which the rounds will fall. The chief disadvantage of this system are the number of personnel required and the extensive post experiment data reduction.

c. Sound Range System. The sound ranging set, GR-8, is capable of recording sound waves in an area of the size required. The GR-8 is obsolete and its availability is not assured. The azimuth to the center of impact is calculated from the time difference of the sound wave arriving at each microphone in two triangular arrays. The accuracy of the system is dependent primarily on wind conditions and the accuracy of the microphone locations. Irregular terrain in the impact area results in some masking and inaccuracy. Extraneous noises in the area also can adversely affect the operation of the system. This system also limits the firing rate.

d. Acoustic System. An acoustic point of impact system has been developed by Picatinny Arsenal. This system depends on the same principles as the GR-8, but is much more refined in its sensing and recording methods. It uses one large rectangular array. Its developers claim accuracies within a few feet in location and height of burst when measuring bursts of 40mm HE grenades in a 300 yard square target area. This system can be designed to record the point of impact of two artillery rounds impacting within 100 meters of each other with a two second time spacing between bursts provided no other extraneous sounds are in the range area.

2. Measurement of Night Light Intensity.

a. Photometers. Both Spectra-Pritchard and Gamma photometers have been found suitable for measuring night light intensity with the desired degree of accuracy:

(1) By use of a cosine-integrating attachment, the light of the night sky can be reduced to a single point and measured in terms of foot candles. The Spectra-Pritchard is manufactured by Photo Research Corporation and the Gamma by Gamma Scientific Incorporated.

(2) Telephotometer. Such a device is commercially available with a one minute field of view and having the same accuracy as the standard Spectra-Pritchard photometer. The telephotometer will record luminance at greater range from an object than will the standard Spectra-Pritchard photometer. The telephotometer costs approximately $3, 000.

3. Prediction of Night Light Intensity.

A system exists that has the capability of computerpredicting night light intensity at intervals of 15 minutes in units of foot candles. The system is useful for planning purposes and can be used to validate photometer accuracy. The system is limited to a cloudless, polution free atmosphere.

4. Meteorological Instrumentation.

The Meteorological Team has the capability of measuring the following elements continuously at any occurible location:

a. Temperature
b. Humidity
c. Barometric pressure
d. Visibility
e. Wind velocity
f. Wet Bulb Glove Temperature Index
g. Cloud type, amount and height
h. Weather phenomena

5. Simulation Devices.

a. Capability exists to simulate the following weapons by flash, noise, and in some cases, smoke.

(1) Rifle
(2) .30 cal machine gun
(3) .50 cal machine gun
(4) 106 recoilless rifle
(5) 105mm gun, tank mounted

Simulators cost $1,000 each, and five months lead time is required for procurement.

b. Other commercially available simulators are:

(1) Artillery shell impact and land mine simulators. These produce primarily noise and flash, although some smoke and dust are created. Cost of this simulator is estimated at $5,000.

(2) Hand grenades. These simulators produce noise and flash, some dust is also created. Cost of each simulator is estimated at $1,000. Six months lead time is required for procurement.

7. DATA COLLECTION AND ANALYSIS.

A. Data Collection

Data to be collected in conducting indirect fire weapons tests are listed below. The list is not exhaustive, as it is anticipated that development of test methodology will result in additional requirements.

(1) Point of impact for each projectile. Raw data will consist of output from the geophone array transmitted via land line to a multiple channel recording device (tape or oscillograph) accompanied by a timing pulse. Calculation of point of impact will be performed by computer. A procedure for locating impact within a circular geophone array is appended to this section for illustrative purposes.

(2) Time required to respond to a fire request. Several methods may be used to measure response time. The simplest employs observers equipped with stopwatches and data sheets. If all communication between FO, FDC, and weapon crew is recorded, response times may be extracted from the voice data. Test participants, in this instance, would be required to indicate the occurrence of events by identifiable vocal signal. A third method would equip the FO, FDC, and crew with a device to read out a master clock into a data tape on occurrence of a significant event (e.g., begin fire for effect).

(3) Round count. Firing of a round can be sensed by acoustic instrumentation in the vicinity of the weapon, and transmitted to the data collection center by wire or radio link. Rates of fire for indirect fire weapons are relatively low, and it is not anticipated that round counting will pose any serious problems. For correlation purposes, the time associated with each round will be recorded.

(4) Communications. Fire requests, fire adjustment data from the FO, and other tactical communication via voice link will be recorded along with associated time tags. For short range indirect fire weapons (i.e. grenade launchers) where adjustment information may be given

by hand or arm signal, observers equipped with watches and data collection forms will be used.

(5) Environmental data. These data will be recorded on data collection forms at appropriate intervals during the conduct of weapons tests, and will include the following:

(a) Time of day (or night)

(b) Wind velocity and direction

(c) Temperature

(d) Humidity

(e) Target visibility (from FO)

(f) Light level

(6) Range Configuration. These data include observer-target range and weapon-target range for a given test or series of tests.

B. Data analysis.

Data analysis is considered in three phases: reduction of ray data to digital form, correlation of events data, and statistical analysis of reduced and correlated test data to obtain objective results of weapon tests.

(1) Data reduction. This encompasses such tasks as deriving points of impact from geophone data, accumulation round counts, and digitizing manually collected data for subsequent computer analysis.

(2) Correlation. This task consists of organizing data collected on different media by time tag to recreate the actual sequence of events.

(3) Statistical analysis. Statistical techniques to be employed in analysis of test data include the following:

(a) Analyses of variance and covariance

(b) Chi-square test

(c) Least-squares fitting

(d) F-test

(e) t-test

Detailed descriptions of the application and usage of these procedures may be found in any standard test on statistics and probability.

C. Sample calculation. To illustrate the use of a computer in reduction of test data, the procedure for deriving point of impact from the output of a circular geophone array is presented.

Given any even number of sensors on the surface consider two at a time on opposite ends of a diameter. Assume that one effective velocity from impact to sensor can be found and used. Then:

$$v\Delta t_1 = \sqrt{(a+x_o)^2 + y_o^2} - \sqrt{(a-x_o)^2 + y_o^2}$$

$$\text{Let } k_1 = \frac{v\Delta t_1}{a}, \quad u = \frac{x_o}{a}, \quad v = \frac{y_o}{a}, \quad k_2 = \frac{v\Delta t_2}{a}$$

$$k_1 = \sqrt{(1+u)^2 + v^2} - \sqrt{(1-u)^2 + v^2}$$

Δt_1 = time difference between geophones at (a,0), (-a,0)

$$k_2 = \sqrt{u^2 + (1+v)^2} - \sqrt{u^2 + (1-v^2)}$$

Δt_2 = time difference between geophones at (0,a), (0,-a)

$$u^2\left(1 - \frac{4}{k_1^{\,2}}\right) + v^2 = \frac{k_1^{\,2}}{4} - 1$$

$$u^2 + \left(1 - \frac{4}{k_2^{\,2}}\right) v^2 = \frac{k_2^{\,2}}{4} - 1$$

Let $\alpha = \left(1 - \frac{4}{k_1^{\,2}}\right)$, $\beta = \left(1 - \frac{4}{k_2^{\,2}}\right)$

$$u^2 = \frac{\beta(2\alpha - \alpha\beta - 1)}{(\alpha\beta - 1)(1 - \alpha)(1 - \beta)}$$

$$v^2 = \frac{\alpha(2\beta - \alpha\beta - 1)}{(\alpha\beta - 1)(1 - \alpha)(1 - \beta)}$$

$a < 0$, $\beta < 0$ or else shot landed outside of range

$u^2 < 0$ or $v^2 < 0 => \alpha\beta - 1 < 0 =>$ shot landed outside of range

$1 - \alpha > 0$

$1 - \beta > 0$

$\alpha\beta - 1 = 0 > \alpha = \beta = 1$, but $\alpha < 0$ so $\alpha\beta - 1 \neq 0$

The quadrant is known from order of arrival times.

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ANNEX A
TITLE BIBLIOGRAPHY

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2. FM 6-122 - Artillery Sound Ranging and Flash Ranging.

3. FM 7-24 - Communication in Infantry and Airborne Divisions.

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5. FM 11-30 - Signal Corps Technical Intelligence.

6. FM 11-84 - Signal Radio Operations Company.

7. FM 11-117 - Signal Support Company.

8. FM 11-137 - Signal Communications Center Operation Company.

9. FM 20-60 - Battlefield Illumination.

10. FM 21-6 - Techniques of Military Instruction.

11. FM 21-26 - Map Reading.

12. FM 21-30 Military Symbols.

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23. FM 24-18 - Field Radio Techniques.

24. FM 24-20 - Field Wire and Field Cable Techniques.

25. FM 30-10 - Terrain Intelligence.

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35. A Subj Scd 6-13 - Operation of Fire Direction Center.

36. A Subj Scd 6-17 - Liaison.

37. A Subj Scd 6-21 - Operation of Meteorological Sections.

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ABSTRACT BIBLIOGRAPHY

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(1) This manual provides doctrinal guidance on the organization and tactical employment of each Rifle Platoon and squad organic to the infantry, airborne, and mechanized Rifle Company.

(2) The material contained in this manual is applicable to nuclear and nonnuclear warfare.

(3) With few exceptions, the material in this manual applies equally to the three types of platoons (infantry, airborne, and mechanized). Minor organizational and equipment differences and changes do not effect the basic guidance where differences do exist in the employment of the types of Rifle Platoon, they are so indicated.

(4) New and improved weapons and equipment are continually being developed and tested for the Rifle Platoon; therefore, no specific nomenclature is given for automatic weapons, grenade launchers, or anti-tank weapons. Ther small unit leader must adopt the tactics and techniques in this manual to fit the weapons and equipment of his unit.

(5) This manual must be used in conjunction with FMs 7-11 and 17-15.

2. FM 31-50 - Combat in Fortified and Built-up Areas.

ABSTRACT: Purpose and Scope.

(1) This manual provides guidance to commanders and staff officers in the fundamental doctrine and tactical principles of combat in fortified and built-up areas.

(2) This manual is divided into two parts. Part one describes the characteristics, tactical considerations, and doctrine and techniques for the tactical employment of units in fortified areas. The material focused largely upon operations below division level to emphasize the unusual nature of operations in fortified and built-up areas at lower levels.

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ABSTRACT:

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ABSTRACT:

(1) This investigation is concerned with various measures of what can be seen from an observation point above the ground. 2 Several rolling fields in the Baltimore, Maryland, area have been surveyed to provide the necessary data. These data are compared with and supplemented by those derived directly from topographical maps of the same fields. The feasibility of using these maps alone is discussed.

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ABSTRACT: (None)

LITTON SUMMARY:

This paper describes a series of tests made on the Redesigned Sight System of the M79 Grenade Launcher to determine its suitability. The following tests were conducted:

1. Physical Characteristics.
2. Sight Calibrations and Accuracy.
3. Field Firing.
4. Durability, Reliability, and Maintenance.
5. Human Factors Engineering.

6. Safety Confirmation.
7. Flat Trajectory Sight.
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ABSTRACT:

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(2) Experimental tests to determine maximum range, range dispersion and recoil characteristics were requested by HQ, US Army Material Command and are presented herein. A history sketch of the M79 Weapon System is also presented as background information, and describes the various rifle attachments and launch systems considered during the early stages of development of the 40mm program.

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8. 40mm Automatic and Semi-automatic Grenade Launchers, Technical Information Report 27.1.3.1, Interim Report, AMC, March 1966.

ABSTRACT:

Automatic and semi-automatic 40mm Grenade Launchers are needed to increase the firepower of infantry squads. Such weapons must be light enough to be carried by one man, must be accurate, and must be able to deliver devastating fire than can be quickly shifted from point to point. Two launchers, one a low-velocity model with straight blowback operations and the other, a high-velocity model with short recoil operation and firing from an open bolt, are being developed. The low-velocity launcher can be fired from bipod or from an M-2 tripod ground machine gun mount. Both launchers can be mounted on vehicles, aircraft, or patrol boats. The low-velocity (250 feet per second) gun has an effective range of about 400 meters and the effective range of the high-velocity (790 feet per second) gun is 2,200 meters.

9. Engineering Test of 40mm XM148 Grenade Launcher Attachment for the XM16E1 Rifle (U), USATECOM, Aberdeen Proving Ground, Maryland (C66-2293).

ABSTRACT (U):

Five 40mm XM148 Grenade Launcher Attachments for the XM16E1 Rifle were submitted to D and PS for an engineering test. The purpose of the test was to determine if the XM148 Launcher Attachment and the XM16E1 Rifle are functionally compatible and to compare the capabilities and limitations of the XM148 Launcher with those of the M79 Launcher. Testing began on 10 May 1965 and was completed on 5 January 1966. Approximately three months of the test period were expended on test suspension and retesting of modifications to the XM148 Launcher. The XM148 Launcher and the XM16E1 Rifle were determined to be functionally compatible, except that the launcher sight may fail to retain a sight setting during firing of the rifle and launcher. The over all performance of the XM148 Launcher was not equal to that of the M79 Launcher. It was recommended that the XM-148 Launcher sight deficiencies and other shortcomings be resolved to accommodate tactical use requirements. Also, that X M148 Launcher Attachments of the final configuration be tested sufficiently to verify the adequacy of correction of the deficiencies and shortcomings and to ascertain the suitability of launchers produced by die casting techniques.

10. A Mathematical Model to Determine the Vulnerable Area of A Fragment Sensitive Target (U), Naval Weapons Laboratory,

Dahlgren, Virginia, Robert D. Webster, 10 June 1965 (C66-1243).

ABSTRACT:

A mathematical model is developed to determine the vulnerable area of a fragment-sensitive target from various aspects. Although the model was designed specifically to consider electronic equipment, it is generally applicable to any target which can be represented by an aggregation of rectangular parallelipeds provided that the material and material thickness can be determined for all components.

11. Methods for Computing the Effectiveness of Fragmentation Weapons Against Targets on the Ground, BRL Report Number 800, BRL, Aberdeen Proving Ground, Maryland.

ABSTRACT:

This report is a collection of material relating to the assessment of the effectiveness of fragmentation type weapons against targets on the ground. It contains computational methods for obtaining "lethal areas", single shot probabilities of kill, and area coverage capabilities. The weapons considered are similar to fragmenting artillery shell, rockets, and guided missile warheads. Overall effectiveness of such weapons depends upon their weight, the number and size of the fragments, the initial fragment velocity, the degree of protection offered by the ground or by foxholes, the presented area of each target, the accuracy of aim of the weapon and so on, and the report shows how influence of these quantities on overall effectiveness can be determined.

12. The Statistical Evaluation of Lethal Area (U), Picatinny Arsenal, Dover, New Jersey, April 1965 (S66-1246).

ABSTRACT:

A statistical model is derived that estimates the amount of variation one may expect in lethal area when fragment mass and initial fragment velocity are treated as random variables. Results from this analysis are compared for a particular case with an analogous Monte Carlo program.

13. The Effectiveness of an Area Weapon, Memo Report Number 1080, USA, BRL, Aberdeen Proving Ground, Maryland, 1957 (U57-383).

ABSTRACT:

Formulae are given for the effectiveness of one or two independent shots by an area weapon against a distribution of targets. These results, together with known techniques, produce estimates for the effectiveness of more than two shots. The results are applicable in cases of fairly general kill probabilities and target distribution.

14. Analytical Methods of Assessing the Performance of Area Fire Weapon Systems, Canadian Armament Research and Development Establishment, Valcartier, Quebec, J. E. Neilson, June 1965 (U66-354).

ABSTRACT:

Several analytical methods are developed for assessing the performance of area fire weapon systems which incorporate warheads designed for the overhead attack of targets. The "mean expected casualty rate" or fraction killed is used as a measure of weapon performance and is computed directly from such factors as the ballistic dispersion and weapon laying errors, target vulnerability, density of fire and the number of shots fired. Included as well are a number of carpet plots which illustrate how performance may be optimized and what maximum levels of performance may be achieved. In addition, a few Monte Carlo investigations were performed in order to verify and to assess the value of the analytical methods proposed.

ANNEX B

HUMAN FACTORS

1. PURPOSE

The purpose of this annex is to present human factors considerations which are pertinent to the planning and execution of various tests to be conducted on the indurect fire range.

2. GENERAL

a. The objective of the indirect fire range is to determine the relative performance of the man/weapon systems selected for comparison.

b. This annex addresses:

(1) Human factors data.

(2) Combat realism.

(3) Motivation of test subjects.

(4) Unit proficiency.

(5) Leadership as a variable.

3. HUMAN FACTORS DATA

A. Data should be obtained before the test runs from the various subject personnel. These data must be analyzed to provide for proper balancing of subjects so that results may undergo valid comparisons. Also, the data will be used to describe the player population, and for purposes of data analysis.

b. Subject Data

(1) MOS

(2) Experience in MOS and proficiency rating where available

(3) Amount of combat experience

4. COMBAT REALISM

One of the most difficult aspects of evaluating the effectiveness of a military weapon system on a test range is to incorporate into the various tests the physiological and psychological stresses found in the combat environment.

a. In testing, the creation of a realistic combat environment can be partially accomplished by requiring subject personnel to perform operationally realistic tasks over extended periods of time.

b. Recent studies of the performances of sleep-deprived individuals have paid increasing notice to mental lapses or pauses on the part of the experimental subjects. These lapses have been observed to increase in frequency and duration as sleep loss progressed.

c. Motivational factors are particularly important in determining whether or not performance on a short-lasting task will be impaired due to sleep deprivation. The novelty of performing a task as a departure from a normal sleep deprivation regimen has helped to account for the lack of performance decline found in many sleep-deprivation studies. The cost of achieving a nondegraded level of performance may be important in the long run as it does require extra effort from the subjects.

d. Monotonous situations increase the effects of sleep deprivation. Monotonous environments also increase the frequency and duration of mental lapses due to sleep deprivation. It seems likely that a monotonous environment will compound the deleterious effects sleep deprivation has on vigilance performance.

e. One form of psychological stress may be assumed to occur whenever the individual is aware of physical danger or a direct threat to his life. Psychological stress is of concern to a commander when it causes degradation of behavior in combat. In combat situations, the psychological stresses resulting from threats to life are the most important causes of psychological disorders among troops, and the duration of an individual's exposure to such threats is probably the best predictor of combat exhaustion.

f. Other forms of psychological stress include the anxieties associated with making decisions with less than full knowledge of the situation, of handling information overloads, and of having to accomplish tasks in less time than is desirable.

5. MOTIVATION

a. A field test with prolonged trials can be expected to make the men fatigued and lethargic. Unless steps are taken to control the motivational levels of the various platoons, unacceptable variations in group performances may result.

b. Gain and Loss Designs. It is most desirable that the scenario provide situations in which the players may either gain or lose, depending upon how well or poorly they perform. The relative cost (loss) and gain of various outcomes must be in proper proportion to induce decision-making by players using subjective expectations similar to those of combat. By making every significant act have some cost or chance for loss or gain, it is possible to introduce some aspects of combat realism.

(1) Such a motivational technique requires that a positive reward be given for every appropriate--realistic--behavior, and that a cost be assessed for every inappropriate--unrealistic--behavior.

(2) The rewards and costs assigned to each individual's behaviors should also have an effect on the possibility of his being declared an overall winner. Pressures to perform realistically would thus be applied to the individuals.

(3) The rewards and costs can be in terms of pre-assigned points. The largest point total must eventually be convertible to some type of prize. The prizes could for instance be three day passes, or even a monetary award.

c. Knowledge of Results

(1) By introducing and manipulating an individual's knowledge of performance results, some control can be exercised over motivation. Desirably, the method of task performance will be controlled by training which is designed to equalize procedures for all individuals so that the effects of the independent variables will not be confounded by individual's inability to follow experimental procedures. The effects of knowledge of performance are many and complex; however, the following findings from previous research should serve as a guide in structuring knowledge of performance for this test.

(a) The greater the task motivation, the more rapidly individual behavior will become goal-directed and precise; thus, a higher level of performance will be reached in a given practice time.

(b) A task develops its own ability to motivate in proportion to the amount of information given the individual about his performance.

(c) The more information that is given an individual, the more precise and directed will be the goal the individual will set for himself.

(d) The less information an individual is given about the outcome of its response, the more likely it is to adopt an inaccurate or inappropriate solution.

(2) To take advantage of these motivational effects, most effectively, the outcome of the individual's responses should be fed back rapidly. The individuals should be informed as to the worth of his actions after their response.

d. Other Motivational Considerations. In a prolonged field test there is a far greater chance of some unforeseen and untoward event causing major perturbations in the data than there is in a short test trial. Some of the possible undersirable occurrences are listed below:

(1) Unusual reward or punitive measures by a unit leader,
(2) A visit to a unit, or the observation of its performance, by a senior officer,
(3) Performing on what is normally a holiday,
(4) The occurrence of a casualty due to the experimental conditions,
(5) Some individuals being given feedback on their levels of performance and some other individuals not being informed about their performances,
(6) Unusual weather conditions,
(7) Unusual equipment failures,
(8) An unusual or missed meal.

7. UNIT PROFICIENCY

a. The proficiency (i.e., readiness) of each group of individuals should be assessed before it makes an experimental run. Only when a unit is declared ready should it be used in the test. This procedure is important in assuring that the different options will be equitably compared and in reducing the differences in performances among replications of the same unit type. The readiness of all units should be assessed by the same set of judges to help assure the application of a standard performance assessment yardstick.

b. The conduct of some form of modified and abbreviated Army training test (ATT) will be required prior to the completion of training. Sufficient time must be allowed following the test to correct noted deficiencies.

ANNEX C 57

POINT OF IMPACT DETERMINATION

During the week of 24 February 1969, experiments were conducted at Fort Benning to evaluate the feasibility of locating points of impact by seismic instrumentation. Summary descriptions of the experiment and conclusions are given here.

Experiment

A single target area, approximately 1 km in diameter, was subjected to a shallow seismic refraction survey. Survey equipment consisted of seismometers, tape recording and playback equipment, and recording oscillographs.

Two perpendicular double ended refraction profiles were made. The sources were two and one quarter pounds of TNT in shot holes that varied in depth from seven to nine feet. The holes were filled and no air wave was observed on the seismograms.

The northwest-southeast trending line is called the four-two shot line and the line perpendicular to this is the three-one shot line. A schematic diagram of the shot lines and the shallow geologic structure is given in Figure 1.

At distances beyond approximately 125 meters and out to 1000 meters the first arriving energy propagates with a velocity of approximately 6.1 km/sec. The "soil" velocity is variable but appears to be roughly 1.69 km/sec in the low lying (areas near shot points one and three) and 1.90 km/sec on the higher ground (shot points two and four). One can hypothesize that the lower areas are filling with relatively uncompacted erosional debris from the higher areas. This leaves the more compacted calcareous soil (seen for example at shot point four) exposed in the high areas.

The interface between the "soil" and the high velocity rock has a slight dip of approximately 18 minutes to the southeast.

The P wave seismic energy observed on the high velocity travel time curves (head wave) from the explosive impact propagates through the soil (velocity v) to the high velocity layer (v_1) (probably limestone) impinges on that layer at the critical angle ($\sin^{-1}\frac{v}{v_1}$) propagates along the interface at the high velocity v_1; and radiates energy back to the surface at the critical angle (see fig. 2). It is the opinion of the seismic interpreter that the first arrival can be read to precision of .0025 sec. Therefore, the time difference observed between sensors is the distance between sensors divided by the velocity v_1 minus corrections due to differences in elevation of sensors, soil velocity variations, and the dip of the interface. Stated in reverse, two situated sources closer together than the distance traveled by the P wave during the length of time representing the timing uncertainty of the system can not be differentiated. At this time this distance resolution would be approximately (.0025 sec) x (6.1 km/sec) $\cong$ 15.25 meters assuming all of the above mentioned corrections are known.

If a distance resolution of 15.25 meters is satisfactory then it is suggested that a circular array of seismometers be used. Moreover, since the velocities involved here are constant, extended use of the seismic array would yield better results by providing successively better values for the several corrections.

If a distance resolution of 15.25 meters is not satisfactory then emphasis can be shifted to the "soil" velocity sections of the travel time curves. Since the P wave traveling in the "soil" is not observed beyond approximately 125 meters a grid of sensors in the shape of squares, hexagons, etc., must cover the target area. Since the "soil" velocity varies slightly over the target area the computer must use different velocities in different areas or the seismometer grid must be made fine enough to negate the effect of the differences. However, the soil velocities are reasonably low so distance resolution will be approximately (.0025 sec) x (2 km/sec) = 5 meters. [redacted]

An even finer spacing of seismometers (d< 15 meters) could eliminate the need for a computer entirely. If all seismometers on a single grid line were wired in series then the output on two perpendicular grid lines would immediately locate the impact within 15 meters. The observation of the times of arrivals of pulses at the grid line outputs could increase this resolution considerably.

See Tab A of Appendix IV for details of this study.

Conclusions and Recommendations

The seismic survey of the target area at Fort Benning indicates a two layer geologic structure. The uppermost layer has a velocity that varies from 1.67 km/sec to 1.95 km/sec. The second layer has a velocity of 6.1 km/sec and is not horizontal with its depth below the arbitrary datum level varying from 51.5 m to 24 m. The strike of this structure is very nearly along the one-three shot line.

This structure admits at least three different methods for mortar impact location. The first would use the 6.1 km/sec layer and yield a distance resolution of approximately 15 m. It is envisioned that a circular array of roughly sixteen seismometers surrounding the target area would provide the 15 m resolution after some use. Actual operation would be required to accumulate and store the various site corrections for elevation, soil velocity variations, and precise dip of the layer.

The second method would use the "soil" layer yielding a resolution of approximately 5 m due to the much lower P wave velocities in the soil. However, more sensors will be required and the accumulation and storage of timing corrections will still be necessary. Various geometries are given here with a minimum of 25 seismometers required. Increasing the number of sensors increases the number of separate solutions for each computed location.

The third method eliminates the need for a computer by using a very dense (spacing, d 15 m) array of seismometers. If the grid is fine enough the geologic variations become unimportant, and one is in effect locating the impact of the mortar shell upon a "continuous" blanket of instruments.

ANNEX D

DOCTRINE

A. Mortar Testing

The elements of U. S. doctrine applicable to weapons testing on the Indirect Fire Facility are those pertaining to the combat use of 60 mm and 81 mm mortars.

An indirect fire test commences with the FO assuming his position at a predetermined observation post (OP). The FO may be equipped with visual aids (binoculars, sighting scopes) or passive night vision devices (PNVD0 in the case of testing under low illumination conditions.

Upon detection of the first target, the FO issues a fire request to the mortar and FDC crews, who move forward to locations selected for mortar emplacement and for the FDC. The nominal mortar crew will consist of a squad leader, one gunner, one assistant gunner, and two ammunitions bearers (TOE 7-16E, Hq., Dept. of Army, 15 July 1963). The FDC crew will consist of a section leader, one or more fire direction computers, and one or more radio telephone operators.

The FO estimates target direction and range, relative to the OP, and relays this information to the FDC. The FDC crew plots target location on a grid containing the (known) locations of the OP and weapon. Target range and bearing relative to the mortar are read from the grid and transmitted to the mortar crew.

Upon delivery of the first round, the FO observes the burst, and calls for a correction (if necessary) to bracket the target on the second round. For example, if the first round falls short, a correction to obtain a second impact beyond the target is called for. The FO then attempts to "split" the bracket for each subsequent round until fire has brought sufficiently close to target to permit fire for effect.

Fire shift is accomplished by calling for fire upon a subsequent target in terms of range and bearing corrections relative to the current target--OP line.

Night operations using illumination ammunition are similarly conducted, with the exception that the FO must also correct burst height to achieve maximum illumination on target.

ANNEX E

FORWARD OBSERVER PERFORMANCE

Objective comparisons of indirect fire weapons are adversely affected by the necessity of incorporating forward observers as an integral part of the fire control system. Individual differences in the abilities of forward observers to acquire and identify targets, to estimate distances and directions, and to adapt to a variety of seeing conditions, stress, and fatigue may be far greater than the inherent differences in performance among the weapons themselves. Therefore, it is mandatory that measures be taken to assure that observer selection does not introduce an unknown bias into the test. Several methods for normalizing expected forward observer performance will be discussed below.

(1) Observer selection. Forward observers should be selected at random from a group whose members are rated close to the established norm in proficiency.

(2) Testing. A prior testing of ability to estimate burst positions can be carried out in a controlled manner by exploding preset charges at known locations within view of the observer, and correlating observer estimates of range and bearing with the true values.

(3) Target location. Targets should be clearly visible to the observer in order to minimize the effects of individual differences in visual acuity and experience in target detection and indentification.

GLOSSARY

ACCURACY: The radius about a mean center of impact within which one-half of a series of rounds from a given weapon with fixed aim will fall (see CIRCULAR ERROR PROBABLE).

ACQUISITION: Detection, location and identification of targets in sufficient detail to permit effective employment of weapons.

AREA TARGET: A target consisting of an area on the ground rather than a point or single object.

BIAS: The distance between the aim point and the mean center of impact.

BRACKETING: The placement of rounds along the weapon-target line such that the target lies between any two successive rounds.

CIRCULAR ERROR PROBABLE (CEP): The radius of a circle with center at the point of aim in which one-half of rounds fired from a given weapon will impact.

DISPERSION: Distribution of fire about a mean center of impact.

FIRE DIRECTION CENTER (FDC): The FDC receives target and burst location data from the FO and transforms these data into fire commands to the mortar squad.

FIRE FOR EFFECT (FFE): Fire intended to achieve the desired effect on the target.

GEOPHONE: A sensing device which generates an electric impulse in response to a seismic stimulus.

HARDENED TARGET: A target which is not subject to destruction by the weapon being tested.

MAINTAINABILITY: A measure of the degree to which system malfunctions can be eliminated or corrected by field personnel.

PASSIVE NIGHT VISION DEVICE (PNVD): An optical instrument containing an electronic image intensification device to enhance target visibility at low illumination levels.

RELIABILITY: In a given trial, the probability that the system will function properly.

TEST CONTROLS: Fixing (holding constant) or removing independent variables in the conduct of tests in order to isolate significant factors.

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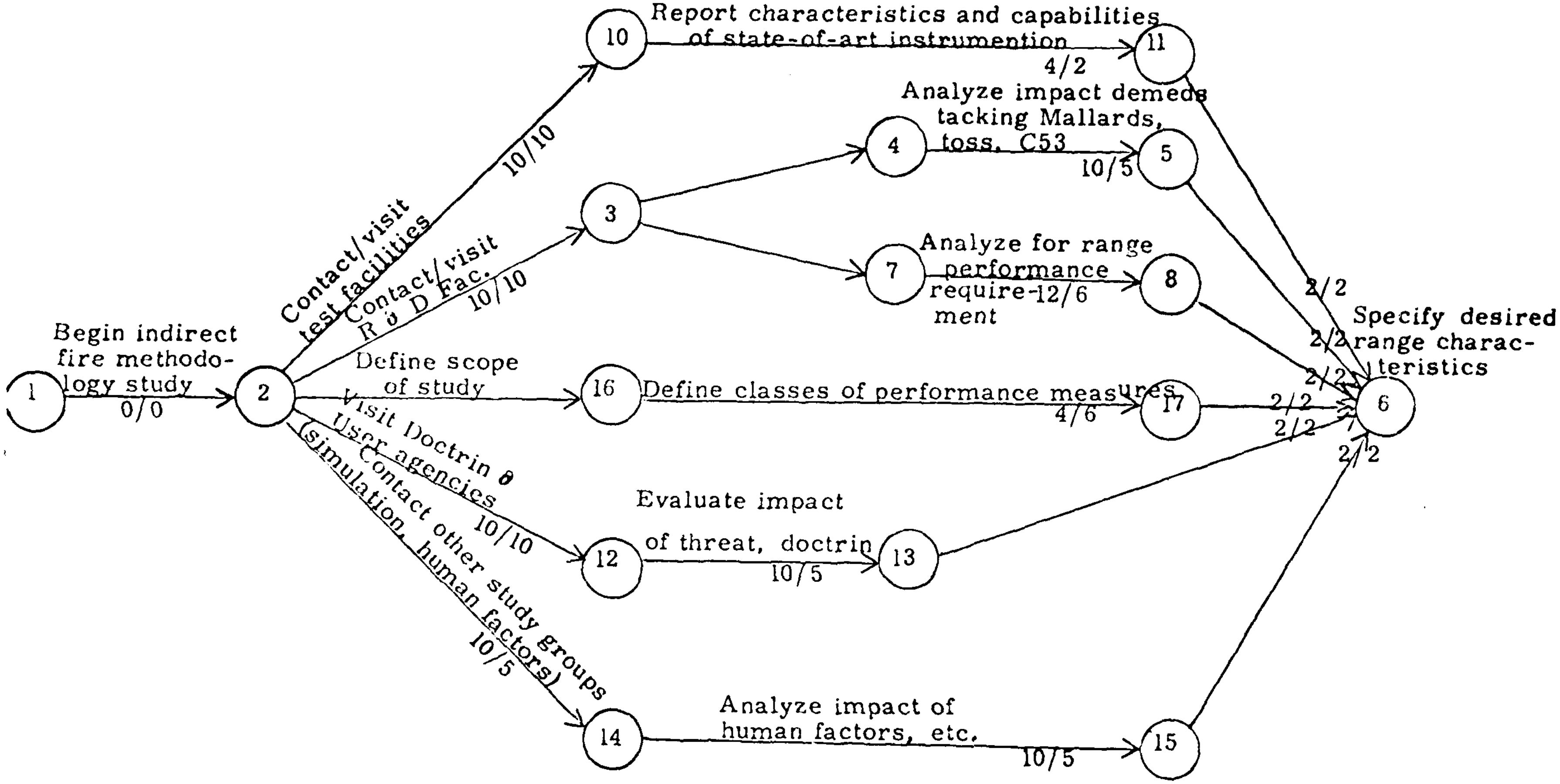
ANNEX G

PERT ANALYSIS

The following pages present a PERT analysis of the indirect fire test methodology study, leading to the development of an Indirect Fire Facility, testing of indirect fire weapons under quasi-combat conditions, and the preparation of a final report.



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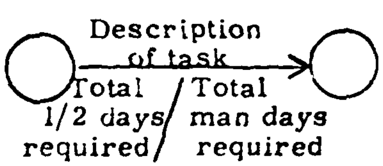
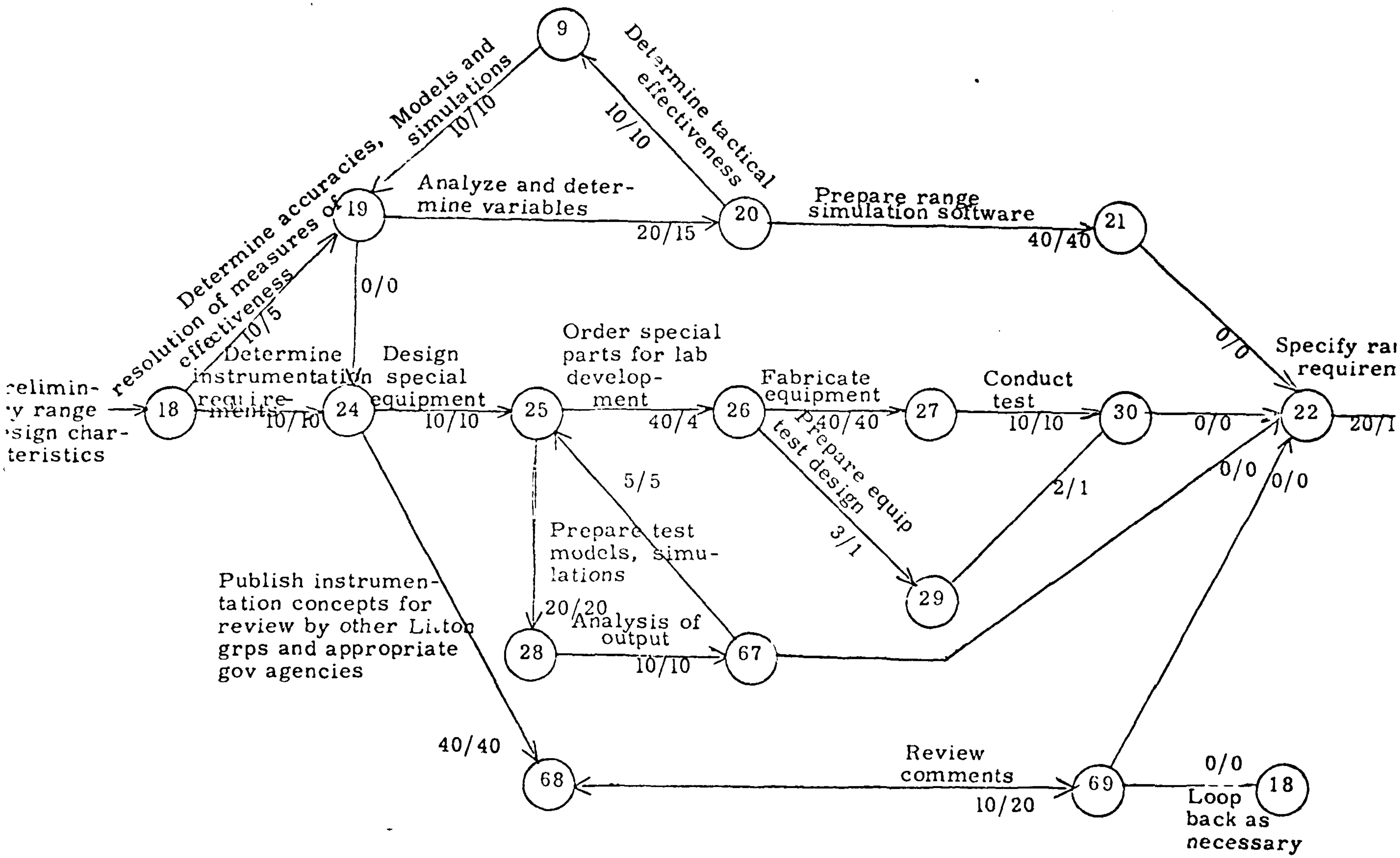


CRITICAL PATH ANALYSIS
INDIRECT-FIRE METHODOLOGY STUDY
UNITED STATES ARMY INFANTRY BOARD



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Determine accuracies, resolution of measures of effectiveness
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Determine tactical effectiveness
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Prepare range simulation software
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Determine instrumentation requirements
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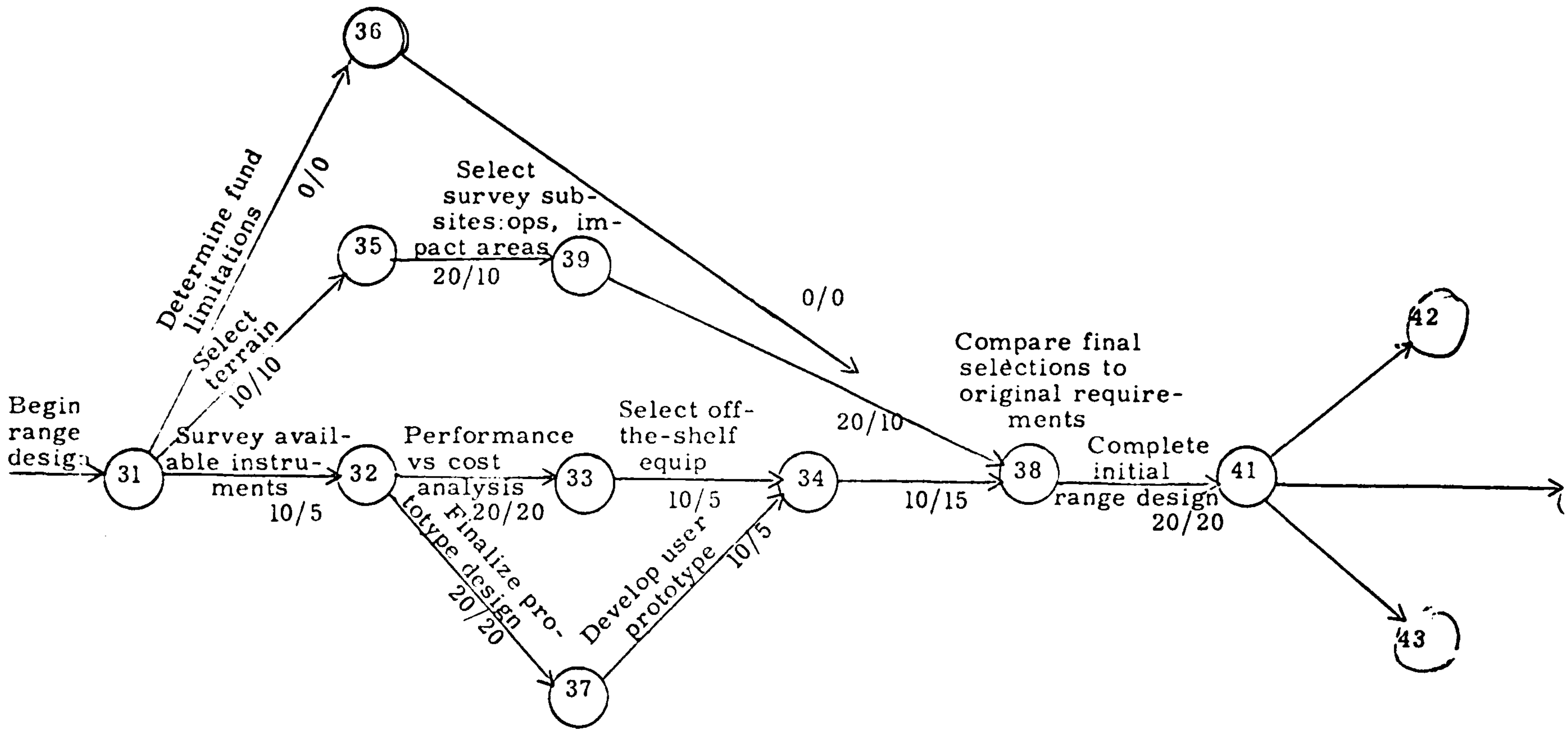

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Select survey sub-sites:ops, im-pact areas
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Survey avail-able instru-ments
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Performance vs cost analysis
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Select off-the-shelf equip
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34
Finalize pro-totype design
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Develop user prototype
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Compare final selections to original require-ments
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Complete initial range design
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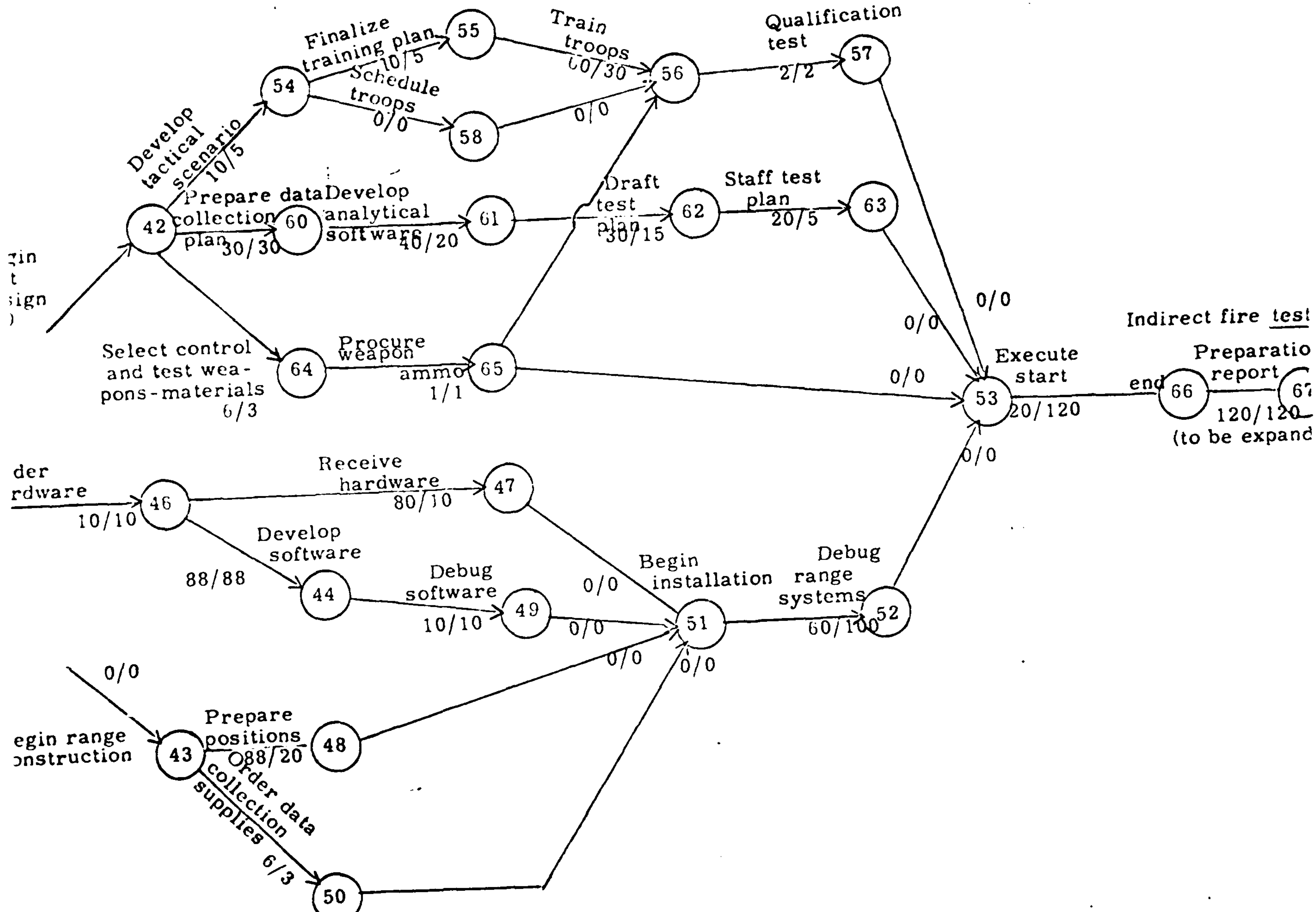

Develop tactical scenario 10/5
Finalize training plan 10/5
Schedule troops 0/0
Train troops 60/30
Qualification test 2/2
Prepare data collection plan 30/30
Develop analytical software 40/20
Draft test plan 30/15
Staff test plan 20/5
Select control and test weapons-materials 6/3
Procure weapon ammo 1/1
Execute start 20/120
Indirect fire test
Preparation report 120/120
(to be expand
end
Receive hardware 80/10
10/10
Develop software 88/88
Debug software 10/10
Begin installation
Debug range systems 60/100
Prepare positions 88/20
Order data collection supplies 6/3
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APPENDIX III

OPERATIONAL TEST METHODOLOGY
AND PROCEDURES

APPENDIX I. OPERATIONAL TEST METHODOLOGY AND PROCEDURES

1. Introduction. This appendix is designed to be a guide for the test officer in implementing operational service tests on mortar systems. Section 2 gives the experimental schedule. Section 3 describes the recommended method for analyzing the data. The analysis does not begin until all firing is completed.

2. Scheduling. The four subtest are described under Technical Objective 2. Subtest 1 is the pre-mission action. Subtest 2 is the fire-mission action. Subtest 3 is the post-mission action. Subtest 4 is deployment. These subtest have individual measures of effectiveness peculiar to the particular subtest. MOE also exist which span the entire subtest. These encompassing MOE are the major concern in this appendix.

Table III-I gives the day firing schedule. Test and control crews should be alternated such that one half the test crews go first in an exercise. Night firing and reduced crew firing follow the schedule as presented in the first soil condition of the day firing table.

3. Analytical Procedure. This section describes an analytical plan recommended for use by the test officer. The plan is designed to analyze the data of the three primary MOE, mission accomplishment, rectangle of dispersion, and offset error. It is assumed that side-by-side tests were conducted using two or more mortar systems. Normally, one mortar system tested is the mortar currently in the inventory and is referred to as the control, although a standard weapon is not necessary. All candidates may be prototype mortars. The plan that follows is only a suggested format for the analysis and should be changed or modified as required. Condition of the data, sample size, and changing environmental conditions during the test may require deviations from the proposed format.

The objective of the plan is to identify the superior weapon as early as possible in the analysis. Once the superior weapon is identified, the data are then analyzed to determine the relative weaknesses and strengths of the selected weapon.

Day Firing Schedule

Table III-I

Soil	Trial	Test Crews (TC) Firing Order 1	2	3	4	5	Control Crews (CC) Firing Order 1	2	3	4	5
Clay Level	1	TC 1	TC 2	TC 3	TC 4	TC 5	CC 1	CC 2	CC 3	CC 4	CC 5
	2	TC 6	TC 7	TC 8	TC 9	TC 10	CC 6	CC 7	CC 8	CC 9	CC 10
	3	TC 11	TC 12	TC 13	TC 14	TC 15	CC 11	CC 12	CC 13	CC 14	CC 15
	4	TC 16	TC 17	TC 18	TC 19	TC 20	CC 16	CC 17	CC 18	CC 19	CC 20
Mud Level	1	TC 6	TC 7	TC 8	TC 9	TC 10	CC 6	CC 7	CC 8	CC 9	CC 10
	2	TC 11	TC 12	TC 13	TC 14	TC 15	CC 11	CC 12	CC 13	CC 14	CC 15
	3	TC 16	TC 17	TC 18	TC 19	TC 20	CC 16	CC 17	CC 18	CC 19	CC 20
	4	TC 1	TC 2	TC 3	TC 4	TC 5	CC 1	CC 2	CC 3	CC 4	CC 5
Sand Level	1	TC 11	TC 12	TC 13	TC 14	TC 15	CC 11	CC 12	CC 13	CC 14	CC 15
	2	TC 16	TC 17	TC 18	TC 19	TC 20	CC 16	CC 17	CC 18	CC 19	CC 20
	3	TC 1	TC 2	TC 3	TC 4	TC 5	CC 1	CC 2	CC 3	CC 4	CC 5
	4	TC 6	TC 7	TC 8	TC 9	TC 10	CC 6	CC 7	CC 8	CC 9	CC 10
Loose Clay Sloping	1	TC 16	TC 17	TC 18	TC 19	TC 20	CC 16	CC 17	CC 18	CC 19	CC 20
	2	TC 1	TC 2	TC 3	TC 4	TC 5	CC 1	CC 2	CC 3	CC 4	CC 5
	3	TC 6	TC 7	TC 8	TC 9	TC 10	CC 6	CC 7	CC 8	CC 9	CC 10
	4	TC 11	TC 12	TC 13	TC 14	TC 15	CC 11	CC 12	CC 13	CC 14	CC 15

a. The Test Situation. Operational performance testing is designed to yield estimates of combat effectiveness in terms of damage inflicted on the enemy. The measures of effectiveness are rectangle of dispersion, offset, and mission accomplishment. Other factors such as reliability are included in the mission accomplishment to the extent that they are in combat for a particular fire mission. In addition, reliability is measured by manually recording the number and types of malfunctions during the course of the service test. Television recordings will also be available to further identify and examine any malfunction that might take place during certain portions of the test.

Twenty crews for each weapon system will perform the fire mission exercise, four times during daylight hours and once under night firing conditions. All crews will perform the fire mission in each soil condition as specified under Objective 2. In addition, each crew will perform the fire mission at reduced strength.

b. Test Criteria. The primary criteria for the evaluation of the mortar system performance are rectangle of dispersion, offset, and mission accomplishment.

(1) Rectangle of Dispersion. Rectangle of dispersion is determined by the range and deflection probable errors.

(2) Offset. Offset is the distance between the center of impact and the primary target location.

(3) Mission Accomplishment. Mission accomplishment is the difference in time between the mission assignment and the mission conclusion.

c. Analysis. The candidate mortar system will be compared using the measures; rectangle of dispersion, offset, and mission accomplishment. Before the new mortar is received by the Infantry Board for service test, it has been subjected to a series of engineering tests to determine its accuracy. However, rectangle of dispersion and offset should be analyzed to check the criteria previously verified by engineering tests. If the new mortar system does not satisfy the criteria at this stage it should be rejected.

(1) Rectangle of Dispersion. The rectangle of dispersion is eight range probable errors by eight deflection probable errors. If all the rounds do not fall within this area then the new weapon system should be rejected. The probable errors as calculated from the USAIB test will be compared with the probable error criteria and if the result of the USAIB firing suggest that the criteria is not met then the mortar system will be rejected.

The probable error is derived from the standard deviation which is derived from the variances. The given probable error is assumed to be the mean of probable errors. From the given probable error a variance (σ^2) is derived and this will be compared with a sample (S^2) calculated from the data. Under the assumption that S^2 is an estimate of σ^2 and that the range and deflection deviations are approximately normally distributed, determine the probability of obtaining a S^2 as large or as small as the sample S^2. If this probability is less than .10 reject the hypothesis that the probable error is within acceptable limits.

The procedure is to calculate the sample variance (S^2) and compare this with σ^2 in the manner shown below:

Determine the probability of obtaining a S^2 as large or as small as the sample $S^2(S_m^2)$ i.e. $P(S^2 \geq S_m^2)$ or $P(S^2 \leq S_m^2)$ given the true variance is σ^2. This is equal to determining the probability that a standard normal variable Z is greater than or equal to Z_1 where $Z_1 = \dfrac{S^2_m - \sigma^2}{2\sigma^4/(n-1)}$

Therefore, if $P(Z \geq Z_1)$ is less than .10 reject the hypothesis.

(2) Offset. Offset is defined to be the difference in meters between the center of impact and the aiming point. The candidate mortar system will be compared with the standard mortar system using mean miss distance of each round from the aiming point. The procedure will be a two-sided t-test. If the hypothesis of equality is rejected then the candidate mortar system will be rejected unless there exist overriding considerations.

(3) If the new mortar system has successfully satisfied, as expected, the accuracy criteria then an analysis of mission accomplishment is performed. This measure includes elements of accuracy, reliability, and responsiveness. All of these

components of combat effectiveness interact within the selected measure. The general linear model is:

$$Y_{ijkl} = U + M_i + S_j + T_k + (MS)_{ij} + (MT)_{ik} + (ST)_{jk} + (MST)_{ijk} + e_{ijkl}$$

where U = the overall mean effect

M_i = i^{th} mortar effect

S_j = j^{th} soil condition effect

T_k = k^{th} trial effect

(MS), (MT), (ST), (MST) = various interaction effects

Y_{ijkl} = observation corresponding to the l^{th} test crew completing the firing mission under the k^{th} ambient light level in the j^{th} type of soil using the i^{th} mortar

e_{ijkl} = random error

Table III-2 gives the analysis of variance table for analyzing the data. Sources of variation marked with a * are important in the context of selecting the superior mortar. Sources of variation marked with a + are to be explored for informational purposes.

(a) If A is a significant F-value then one mortar system is deemed overall superior to the other mortar. A simple examination of the means will provide the information as to how much better one system is. If the degree of superiority is established in clear-cut fashion, i.e., no mortar interactions exist then the mortar has been selected.

(b) If either D or E are significant F-values then a degree of subjectivity has to enter into the determination. The cell means should be plotted as depicted in Figure III-1. If the F-value for A is significant then the interactions are of concern only in the situation as depicted in Figure III-1b. If the mortar deemed inferior by the overall means is superior in one of the cells then the pre-mission activities and the television

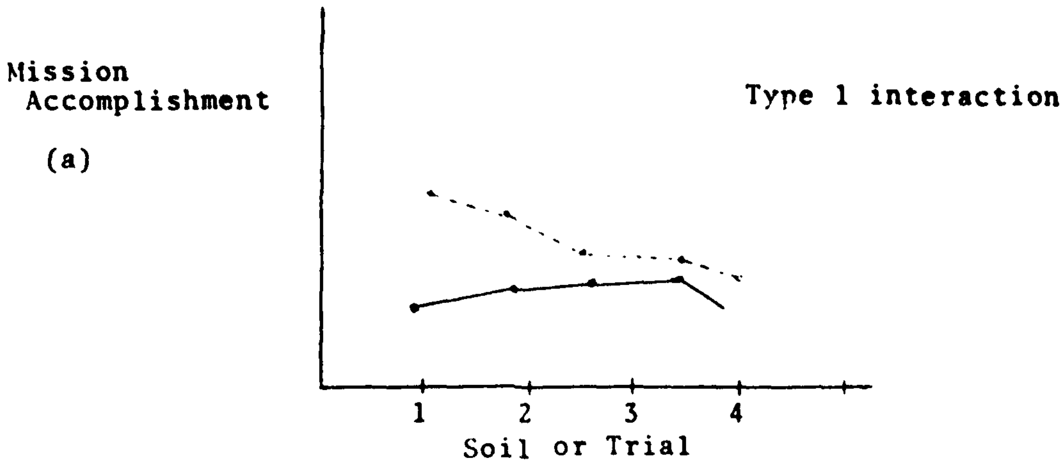
Source of Variation	df	DS	MS	F
Mortar*	1			A
Soil+	3			B
Trial+	3			C
M x S*	3			D
M x T*	3			E
S x T+	9			F
M x S x T+	9			G
Error	128			
Total	159			

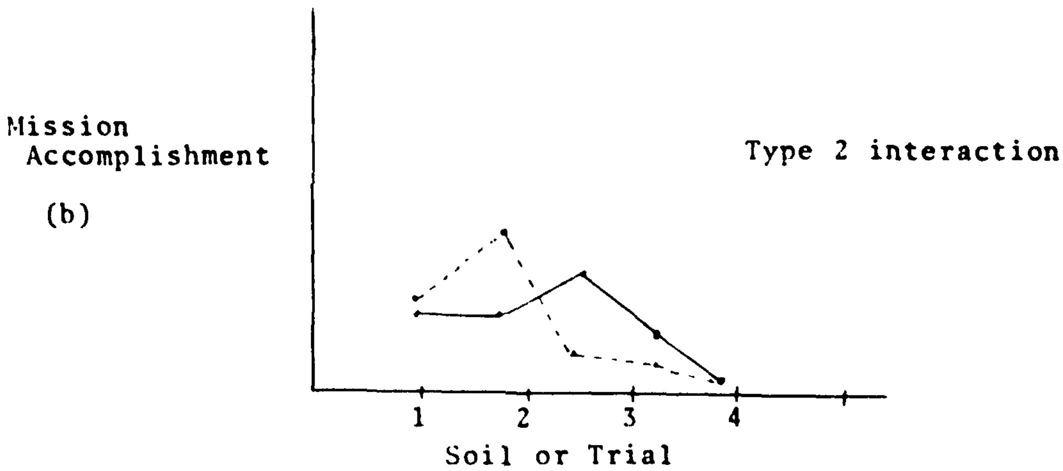
*Of primary concern in the decision process

+Informational sources of variation

Analysis of Variance Table

Table III-2





Mortar x Soil or Trial Interaction Types

Figure III-1

tapes have to be closely observed for aids to decision making. If the A F-value is not significant then select the standard weapon. If, however, a mortar interaction is significant go through the same procedure of observing the video tapes to aid in the decision process.

(c) The analysis is merely an indicator device and does not explain the why's and how's. The video replays will hopefully give the necessary material to establish cause and effect relationships.

4. The analysis of night firing and day firing with reduced crew consist of a t-test. The results of the analysis may prove particularly useful if the day firing fails to provide decision making information. If the results of either the night or reduced crew firing conflict with the results of day firing then subjectivity will have to enter into recommendations or perhaps further test is called for.

VOLUME V

APPENDIX IV

TAB A	PROPOSAL AND FINAL REPORT - GEOLOGICAL SURVEY OF NOLAN RANGE
TAB B	TECHNICAL MEMORANDUM - INTERSECTING LINE MEHTOD OF DETERMINING POINT OF IMPACT BY TRIANGULATION
TAB C	TECHNICAL MEMORANDUM - PROPAGATION OF SOUND IN AIR
TAB D	REPRINTS FROM HANDBOOK OF CONSTANTS - SPEED OF SOUND IN VARIOUS MINERALS AND SOIL TYPES

Form N-3 (Modif.)

THE UNIVERSITY OF MICHIGAN

OFFICE OF RESEARCH ADMINISTRATION

ANN ARBOR, MICHIGAN

TO

Mellonic Systems Development Division
Litton Systems Inc.
1340 Munras Ave.
Monterey, California 93940

Subject PROPOSAL FOR A SEISMIC SURVEY OF THE MORTAR IMPACT RANGE AT FT. BENNING, GEORGIA

THE UNIVERSITY OF MICHIGAN
OFFICE OF RESEARCH ADMINISTRATION
ANN ARBOR, MICHIGAN

PROPOSAL

Date 17 January 1969

TO: Mellonic Systems Development Division
Litton Systems Inc.
1340 Munras Ave.
Monterey, California 93940

The Regents of The University of Michigan (hereinafter called "The University") proposes to conduct for you on a cost reimbursement basis a research program in accordance with the following:

1. *PROJECT:*

The University shall supply the necessary personnel, facilities and materials to conduct a program of research to determine the gross shallow geological structure of a site (one kilometer in diameter) at Fort Benning, Georgia. Specifically the program will be directed toward fulfillment of the following tasks:

1. Provide the seismometers, and associated recording equipment (excluding field recording cable, provided and laid by Sponsor) to record explosive sources provided by the Sponsor at seismometer locations surveyed by the Sponsor.

2. Analyze the seismograms in terms of P wave travel times to determine the gross shallow geological structure of the site.

3. Analyze as many seismograms as time and funds permit in terms of spectral content and P wave attenuation.

4. Provide the Sponsor a "letter type" final report.

2. *CONTRACT PERIOD:*

3. *COSTS:*

Charges to you for this work are to be computed on the basis of the following:

(a) The cost of direct labor and technical supervision.

(b) Indirect costs amounting to 47% ~~33%~~ of the total of the items included in paragraph (a).

(c) The cost of materials consumed in the investigation and of special equipment which it may be necessary for us to purchase, also miscellaneous charges including freight, express, telephone and telegraph charges, traveling expenses, cost of installation of equipment, maintenance of equipment, and other similar incidental costs.

4. *SPECIAL EQUIPMENT:*

With reference to the special equipment which it may be necessary for us to purchase for your account in conducting this investigation, it is understood that except when said equipment forms a part of an apparatus or instrument for the production of which the work in whole or in part was undertaken, said special equipment is to become the property of The University unless otherwise specified herein, or otherwise requested in writing by you within one month after the completion of the work. It is understood that your written approval will be obtained before we purchase any major piece of such equipment.

5. *LIMITATION UPON COSTS:*

It is agreed that the cost to you, including all charges set forth in sub-paragraphs (a), (b) and (c) of Paragraph 3

shall not exceed Six Thousand Nine Hundred and Seventy

Dollars ($ 6,970) without your written approval.

6. *TERMS OF PAYMENT:*

It is understood that you are to pay to The University within thirty (30) days of the receipt of invoices all charges for the research work as specified in this proposal.

7. *GENERAL PATENT RIGHTS:*

It is understood that payment of costs of this project as covered in sub-paragraphs (a), (b) and (c) of Paragraph 3 entitles you to, and you do hereby acquire, an irrevocable, nonexclusive, free license, without guarantee of protection or indemnity, to make, have made for you, use and sell the articles, machines or devices (or the right to practice the process, if a process invention) under any and all patents that may be granted to The University or to any of its employees engaged upon said research work upon any invention resulting from said research work. It is understood that neither The University nor the inventor shall be under any obligation to prosecute any patent application.

8. *INVENTOR'S AGREEMENTS:*

The University agrees to use, in carrying out the research work covered by the provisions of this agreement, only such of The University's employees as shall have executed and delivered to The University contracts known as "Inventor's Agreements,"

9. *REPORTS:*

(a) The University agrees to give you reports of the progress of the above described research project during the term of this contract, including a final report on the termination of the contract.

(b) You shall not use the name of The University in your publicity or advertising without the prior written approval of the Director of Research Administration.

10. *PUBLICATIONS:*

The policy of The University is to encourage staff members to publish significant results of project work that are in the nature of fundamental or general principles. Manuscripts based on the work of this project will be submitted to you before publication for approval of matter pertaining to your proprietary rights.

11. *COMPLETION:*

The University fully expects that the project work will be completed within the time period and cost estimate indicated in paragraphs 2 and 5. However, because of the very nature of research,* The University can make no guarantee of completion of the work within the limits specified in this proposal.

*(insert) and the potential difficulties with the weather,

12. *ACCEPTANCE OF PROPOSAL:*

This proposal has been prepared for your consideration. It will become a contract when and only when it has been accepted by you and approved by the duly authorized officers of The Regents of The University of Michigan.

13. *CHANGES IN CONTRACT:*

All agreements changing the terms of this contract, either in the kind of work undertaken or in the cost, will be valid only if made in writing and approved by the duly authorized officers of The Regents of The University of Michigan.

OFFICE OF RESEARCH ADMINISTRATION

By David M. Plawchan

Administrative Assistant, ORA

The foregoing proposal and contract is hereby accepted and signed in triplicate this

4th day of February 19 69

Litton Systems, Inc.

Mellonics Systems Dev. Div.

By

Title Vice President

Approved for THE REGENTS OF THE UNIVERSITY OF MICHIGAN

this 13th day of February 19 69

as of the 17th day of February 19 69

Willow Run Laboratories

INSTITUTE OF SCIENCE AND TECHNOLOGY
THE UNIVERSITY OF MICHIGAN

COST INFORMATION WORK SHEETS

TITLE Seismic Calibration at Fort Benning, Ga.

Has this proposal been approved by the Laboratory Head? ______
List of Technical Review Committee members who reviewed this proposal:

______

NOTE: If items of GFE are required, attach a list.

I SALARIES AND WAGES: (Including Staff Benefits) — Estimated Cost

Research Engineers	MM	X Rate $		= $	
Associate Res. Engineers	MM 3/4	X Rate	1561	=	1172
Research Associates	MM 1/2	X Rate	1153	=	576
Graduate Res. Assistants	MM	X Rate		=	
Research Assistants	MM	X Rate		=	
U-M Teaching Faculty	MM	X Rate		=	
Technicians	MM 1	X Rate	906	=	906
Assistants in Research	MM 3/4	X Rate	743	=	556
Secretaries	MM 1/4	X Rate	576	=	145
Publications Shop	MM	X Rate		=	
Over time (Technician)	(hr) ~~MM~~ 32	X Rate	8.06	=	273
	MM	X Rate		=	
Instrument Shop	MM	X Rate		=	
360 Computer Personnel Hrs.	Hrs.	X Rate		=	
1401 Computer Personnel Hrs.	Hrs.	X Rate		=	

Total Salaries and Wages $ 3628

II INDIRECT COSTS: (S&W) $ 3355 X Rate 47% = $ 1575

III SPECIAL EQUIPMENT: (Provide breakdown on Page 4.) $ ______

IV TRAVEL: (Provide breakdown on Page 5.) $ 755

V OUTSIDE CONSULTANTS: No. of days___ X Est. rate/day $_____ = $__________
(Indicate name of consultant, why he is required, plus estimated daily rate.)

VI OTHER DIRECT COSTS:

(1) Outside Services (Telephone, TWX, Freight, Postage, etc.) $______

(2) Misc. Supplies & Expense (Office, Store, Service Unit Supplies, etc.) $ 50.00

(3) Electronic and/or Special Supplies (Provide breakdown on Page 4.) $812.00

(4) IBM Computer Use Charge:

(A) IBM 360 (Provide breakdown on P. 6.) = $_____

(B) IBM 1401 ___Hrs.* X ___Rate = _____

Total IBM Computer Use Charges $______

(5) Reports:

(A) ___Qtly. Reports of ___pages and ___copies

(B) ___Tech. Reports of ___pages and ___copies

(C) Final Report ___pages and ___copies

(D) ___Other Reports of___pages and ___copies

Total Report Materials & Supplies $______

(6) Aircraft Costs: (Provide breakdown on special form available from Administrative Services.) $______

Total Other Direct Costs $ 862.00

VII SUBCONTRACTS: (Indicate item to be subcontracted, whether or not sole source, and company, if known.) $__________

VIII List here any costs peculiar to this proposal not covered by the above form. $__________

IX ESTIMATED TOTAL COST OF 2 -MONTH PROGRAM $6820.00

* The number of hours used here must be the same as that used on Page 2, Item I. Current rates are available from Administrative Services.

Willow Run Laboratories

INSTITUTE OF SCIENCE AND TECHNOLOGY
THE UNIVERSITY OF MICHIGAN

Cost Breakdown of Equipment

No. Req'd.	Item	Cost Each	Estimated Cost
		$	$

ESTIMATED TOTAL COST OF EQUIPMENT $

Cost Breakdown of Electronic and/or Special Supplies

No. Req'd.	Item	Cost Each	Estimated Cost
8	rolls of 5-124 7" paper	$14.20	$ 113.60
11	rolls of 5-133 12" paper	52.13	573.43
1	roll 851 1" 3M tape	34.73	34.73
3	line drivers	30.00	90.00

ESTIMATED TOTAL COST OF ELECTRONIC AND/OR SPECIAL SUPPLIES $ 811.76

Willow Run Laboratories

INSTITUTE OF SCIENCE AND TECHNOLOGY
THE UNIVERSITY OF MICHIGAN

Cost Breakdown of Travel & Subsistence

Estimated Cost

Destination: Fort Benning, Ga.

1 Trips for 2 persons for 5 days per trip

Air Fare (2 R.T. @ $96.00) $ 192.00

Subsistence (10 days @ $22 per day)* 220.00

Auto Rental, Taxi, etc. (____ days @ $20 per day) ____

Estimated Cost of Travel to Fort Benning, Ga. (Destination) $ 412

Destination: Fort Benning, Ga.

1 Trips for 1 persons for 9 days per trip

Air Fare (____ R.T. @ $____) ____

Subsistence (9 days @ $22 per day)* 198

Truck ~~xxxxx~~ Rental, Taxi, etc. (____ days @ $20 per day) 145
1/2 Month at 125 per Mo. = 65 Gas and Oil $80.00

Estimated Cost of Travel to Fort Bennin, Ga. (Destination) 343

Destination: ____

____ Trips for ____ persons for ____ days per trip

Air Fare (____ R.T. @ $____) ____

Subsistence (____ days @ $22 per day)* ____

Auto Rental, Taxi, etc. (____ days @ $20 per day) ____

Estimated Cost of Travel to ____ (Destination) ____

(Continued on next page)

* University of Michigan employees are reimbursed for actual expenditures while traveling, when such expenditures are necessary, reasonable and properly documented. A figure of $22 per day is used above for cost estimating purposes.

were fired for location purposes on the four-two shot line. Figure 2 is a typical seismogram of one of the buried shots. Seismometer sensitivity and total system gain are shown. The polarity reversal at 875 m is an equipment problem not a seismic question. Figure 3 is a typical recording of a simulated 4.2-inch mortar impact (2 1/4 lbs of TNT on the surface). It is the opinion of the seismic interpreter that the first arrival can be read to precision of .0025 sec. Figures 4 and 5 display the raw data and a topographic profile of shot line along which it was taken. Figures 6 and 7 show the data corrected to a datum level of 130.17 meters above mean sea level. That is, the differences in elevation of the shots and sensors have been corrected and hence forth all depths are given with respect to this arbitrary reference level. In effect we assume that the shots were fired and all the sensors were located on this plane called the datum surface. Furthermore, a correction of .018 sec was subtracted from all the data to compensate for the delay between the electrical firing impulse and the actual explosion. This delay has also been observed in oil exploration work.

Figure 6 and 7 show the current geophysical interpretation of the data. This interpretation would, of course, change somewhat should further data be collected. However, for the purpose of this study this data is adequate.

Interpretation

At distances beyond approximately 125 meters and out to 1000 meters the first arriving energy propagates with a velocity of approximately 6.1 km/sec. The "soil" velocity is variable but appears to be roughly 1.69 km/sec in the low lying (areas near shot points one and three) and 1.90 km/sec on the higher ground (shot points two and four). One can hypothesize that the lower areas are filling with relatively uncompacted erosional debris from the higher areas. This leaves the more compacted calcareous soil (seen for example at shot point four) exposed in the high areas.

The interface between the "soil" and the high velocity rock has a slight dip of approximately 18 minutes to the southeast.

Impact Location

The P wave seismic energy observed on the high velocity travel time curves (head wave) from the explosive impact propagates through the soil (velocity v) to the high velocity layer (v_1) (probably limestone); impinges on that layer at the critical angle ($\sin^{-1} \frac{v}{v_1}$); propagates along the interface at the high velocity v_1; and radiates energy back to the surface at the critical angle (see fig. 8). Therefore, the time difference observed between sensors is the distance between sensors divided by the velocity v_1 minus corrections due to differences in elevation of sensors, soil velocity variations, and the dip of the interface. Stated in reverse, two situated sources closer together than the distance traveled by the P wave during the length of time representing the timing uncertainty of the system can not be differentiated. At this time this distance resolution would be approximately (.0025 sec) x (6.1 km/sec) $\cong$ 15.25 meters assuming all of the above mentioned corrections are known.

Figure 9 showing attempts made to locate three experimental shots, indicate that such corrections are very important. No corrections for elevation, soil velocity variations or dip were made in the formation of Figure 9. Furthermore Figure 9 shows that a linear array of seismometers even without corrections provides good location in azimuth but very poor in range. This phenomena is stated more precisely in References 1, 2, and 3. It is felt that continued use of a circular array of seismometers with the successive accumulation of corrections stored and used in the computer that a distance resolution of 15.25 meters could be achieved.

If a distance resolution of 15.25 meters is satisfactory then it is suggested that a circular array of seismometers be used to eliminate the problems of the linear array. Moreover since the velocities involved here are constant, extended use of the seismic array would yield better results by providing successively better values for the several corrections. An algorithm for computing locations with a circular array of an even number of sensors is given in the appendix.

If a distance resolution of 15.25 meters is not satisfactory then [illegible] can be shifted to the "[illegible]" velocity sections of the travel time curves. Since the P wave traveling in the "soil" is not observed beyond approximately 125 meters a grid of sensors in the shape of squares, hexagons, etc., must cover the target area. Since the "soil" velocity varies slightly over the target area the computer must use different velocities in different areas or the seismometer grid must be made fine enough to negate the effect of the differences. However, the soil velocities are reasonably low so distance resolution will be approximately (.0025 sec) x (2 km/sec) = 5 meters. Figures 10, 11, and 12 show a few grid ideas with approximate dimensions.

An even finer spacing of seismometers (d < 15 meters) could eliminate the need for a computer entirely. If all seismometers on a single grid line were wired in series then the output on two perpendicular grid lines would immediately locate the impact within 15 meters. The observation of the times of arrivals of pulses at the grid line outputs could increase this resolution considerably.

Seismometers

Figure 13 shows a three-dimensional plot of the spectra of the P wave as a function of distance. The data indicates that a seismometer such as the Geo Space HS-1, 7.5 cps, miniature refraction detector would be adequate. It has relatively high sensitivity (for its type) and is very rugged, so only shallow burial (3 to 4 feet) would protect it from direct impact damage.

Conclusions and Recommendations

The seismic survey of the target area at Fort Benning indicates a two layer geologic structure. The upper most layer has a velocity that varies from 1.67 km/sec to 1.95 km/sec. The second layer has a velocity of 6.1 km/sec and is not horizontal with its depth below the arbitrary datum level varying from 51.5 m to 24 m. The strike of this structure is very nearly along the one-three shot line.

This structure admits at least three different methods for mortar impact location. The first would use the 6.1 km/sec layer and yield a distance resolution of approximately 15 m. It is envisioned that a circular array of roughly sixteen seismometers surrounding the target area would provide the 15 m resolution after some use. Actual operation would be required to accumulate and store the various site corrections for elevation, soil velocity variations, and precise dip of the layer.

The second method would use the "soil" layer yielding a resolution of approximately 5 m due to the much lower P wave velocities in the soil. However, more sensors will be required and the accumulation and storage of timing corrections will still be necessary. Various geometries are given here with a minimum of 25 seismometers required. Increasing the number of sensors increases the number of separate solutions for each computed location.

The third method eliminates the need for a computer by using a very dense (spacing, $d < 15$ m) array of seismometers. If the grid is fine enough the geologic variations become unimportant, and one is in effect locating the impact of the mortar shell upon a "continuous" blanket of instruments.

The selection of the method to be used is, of course, left to the sponsor who must weigh the relative importance of resolution, sensor costs, computer costs, and installation.

Appendix

Given any even number of sensors on the surface consider two at a time on opposite ends of a diameter. Assume that one effective velocity from impact to sensor can be found and used. Then:

$$v\Delta t_1 = \sqrt{(a+x_o)^2 + y_o^2} - \sqrt{(a-x_o)^2 + y_o^2}$$

$$\text{Let } k_1 = \frac{v\Delta t_1}{a}, \; u = \frac{x_o}{a}, \; v = \frac{y_o}{a}, \; k_2 = \frac{v\Delta t_2}{a}$$

$$k_1 = \sqrt{(1+u)^2 + v^2} - \sqrt{(1-u)^2 + v^2}$$

Δt_1 = time diff. between geophones at (a,0), (-a,0)

$$k_2 = \sqrt{u^2 + (1+v)^2} - \sqrt{u^2 + (1-v)^2}$$

Δt_2 = time diff. between geophones at (0,a), (0,-a)

$$u^2(1 - \frac{4}{k_1^2}) + v^2 = \frac{k_1^2}{4} - 1$$

$$u^2 + (1 - \frac{4}{k_2^2})v^2 = \frac{k_2^2}{4} - 1$$

$$\text{Let } \alpha = (1 - \frac{4}{k_1^2}), \; \beta = (1 - \frac{4}{k_2^2})$$

$$u^2 = \frac{\beta(2\alpha - \alpha\beta - 1)}{(\alpha\beta - 1)(1 - \alpha)(1 - \beta)}$$

$$v^2 = \frac{\alpha(2\beta - \alpha\beta - 1)}{(\alpha\beta - 1)(1 - \alpha)(1 - \beta)}$$

$\alpha<0$, $\beta<0$ or else shot landed outside of range

$u^2<0$ or $v^2<0$ => $\alpha\beta - 1<0$ => shot landed outside of range

$1 - \alpha>0$

$1 - \beta>0$

$\alpha\beta - 1 = 0$ => $\alpha = \beta = 1$, but $\alpha<0$ so $\alpha\beta - 1 \neq 0$

The quadrant is known from order of arrival times.

References

Fox, H. L. (1968) Meteorological Techniques for Sound Ranging: Theory of Errors, Interim Report, Technical Report ECOM-0233-2, U. S. Army Electronics Command, Ft. Monmouth, New Jersey.

Fox, H. L. and P. E. Sherr (1967) Meteorological Techniques for Sound Ranging, II, Interim Report, Technical Report ECOM-0233-1, U. S. Army Electronics Command, Ft. Monmouth, New Jersey.

Miller, W. B. (1966) Consideration of Some Problems in Curve Fitting, Technical Report ECOM-5078, U. S. Army Electronics Command, Ft. Monmouth, New Jersey.

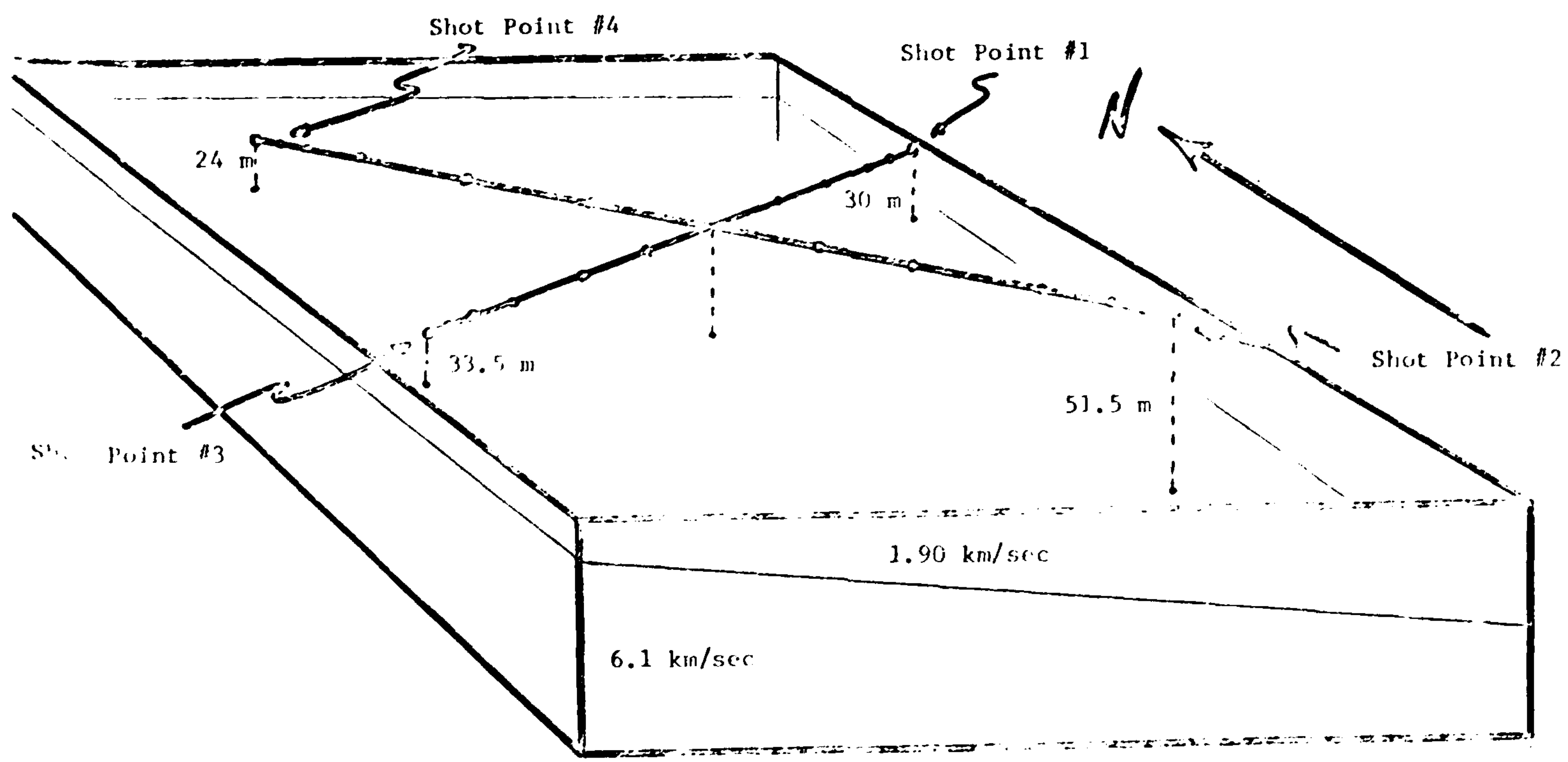
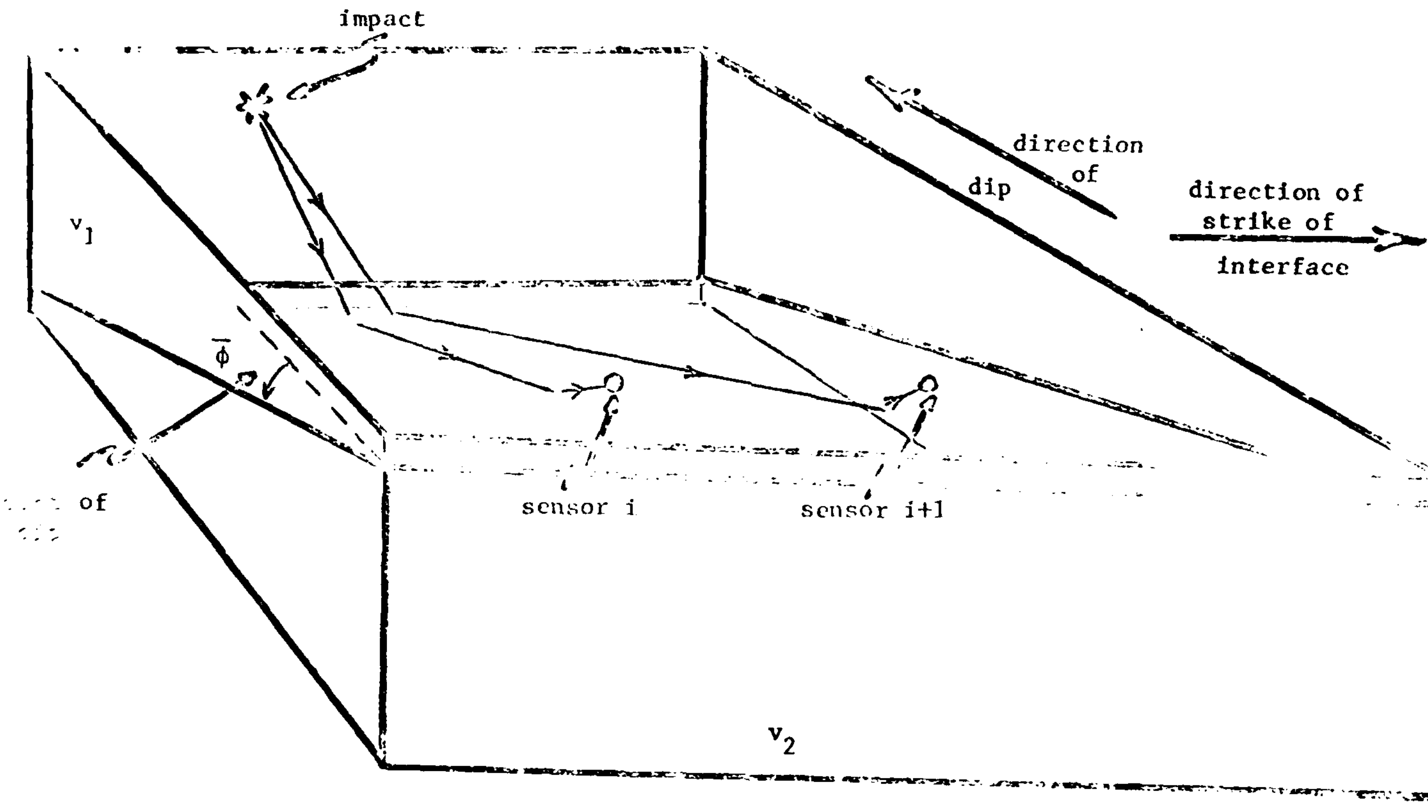


Figure 1. Schematic diagram of the shot lines and the structural interpretation of the data gathered along those lines.



impact
direction
of
dip
direction of
strike of
interface
v_1
$\bar{\phi}$
of
sensor i
sensor i+1
v_2

Figure 1

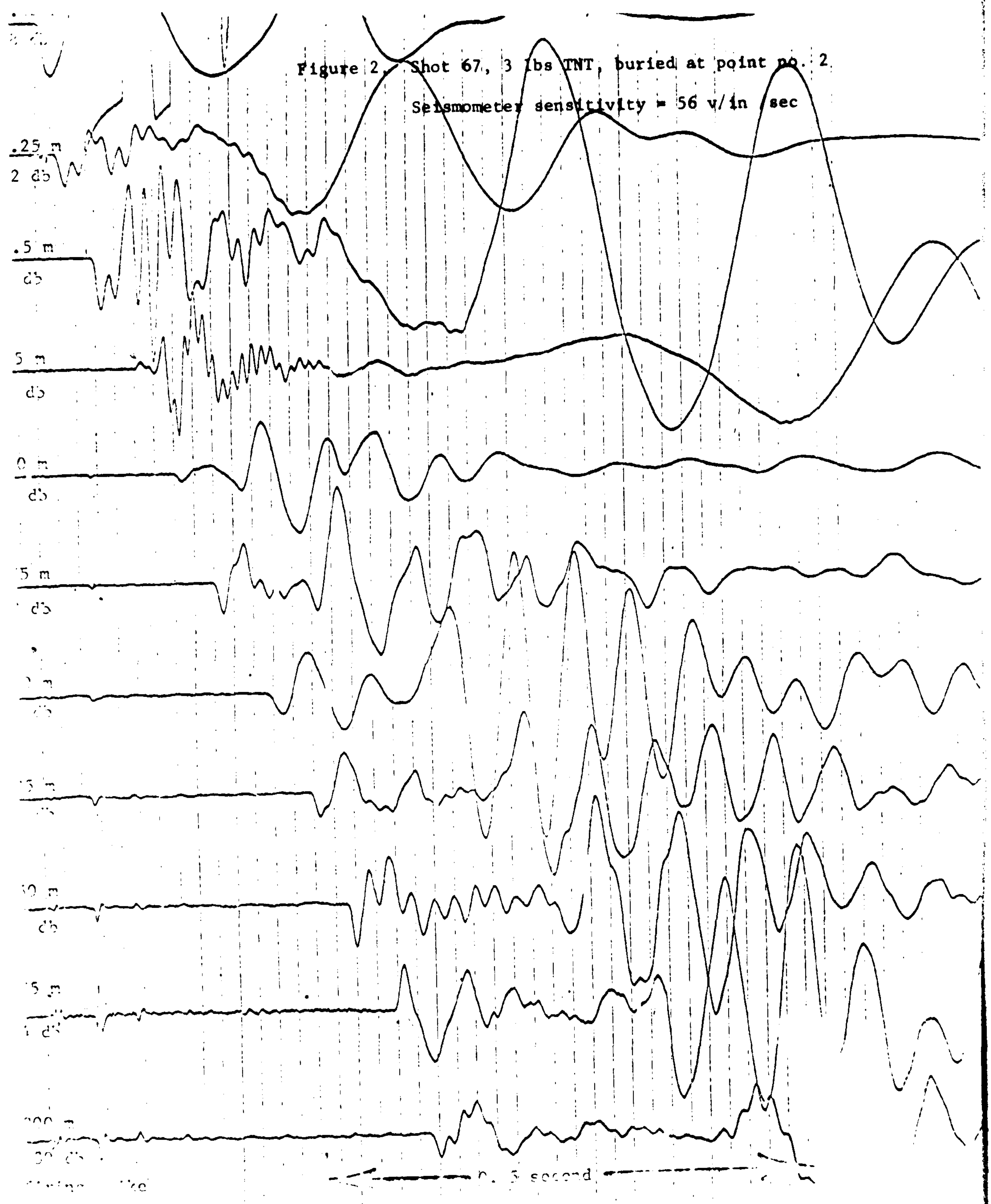
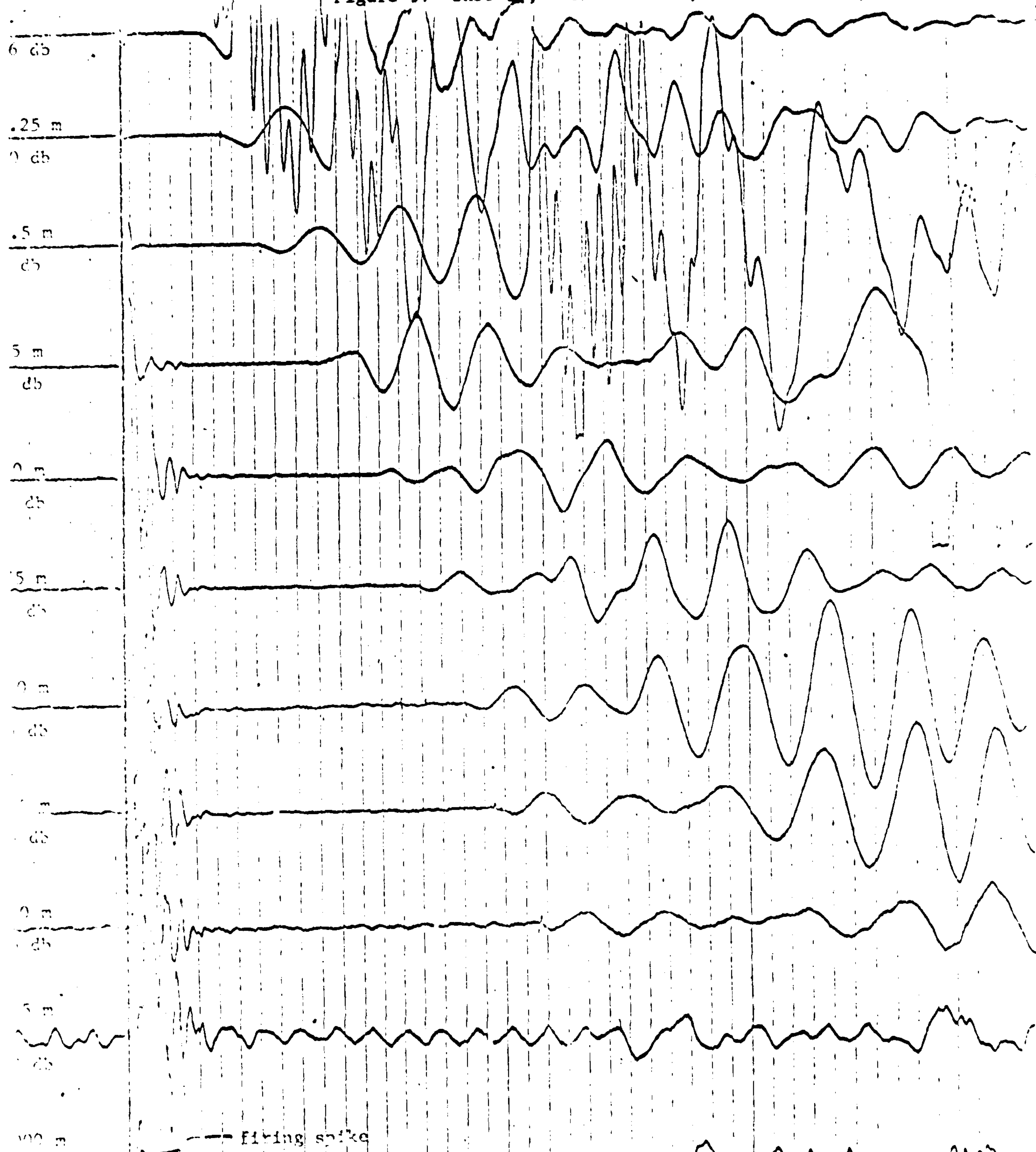


Figure 2. Shot 67, 3 lbs TNT, buried at point no. 2

Seismometer sensitivity = 56 v/in./sec

Figure 3. Shot 12, 2 1/4 lbs TNT, on surface at point2



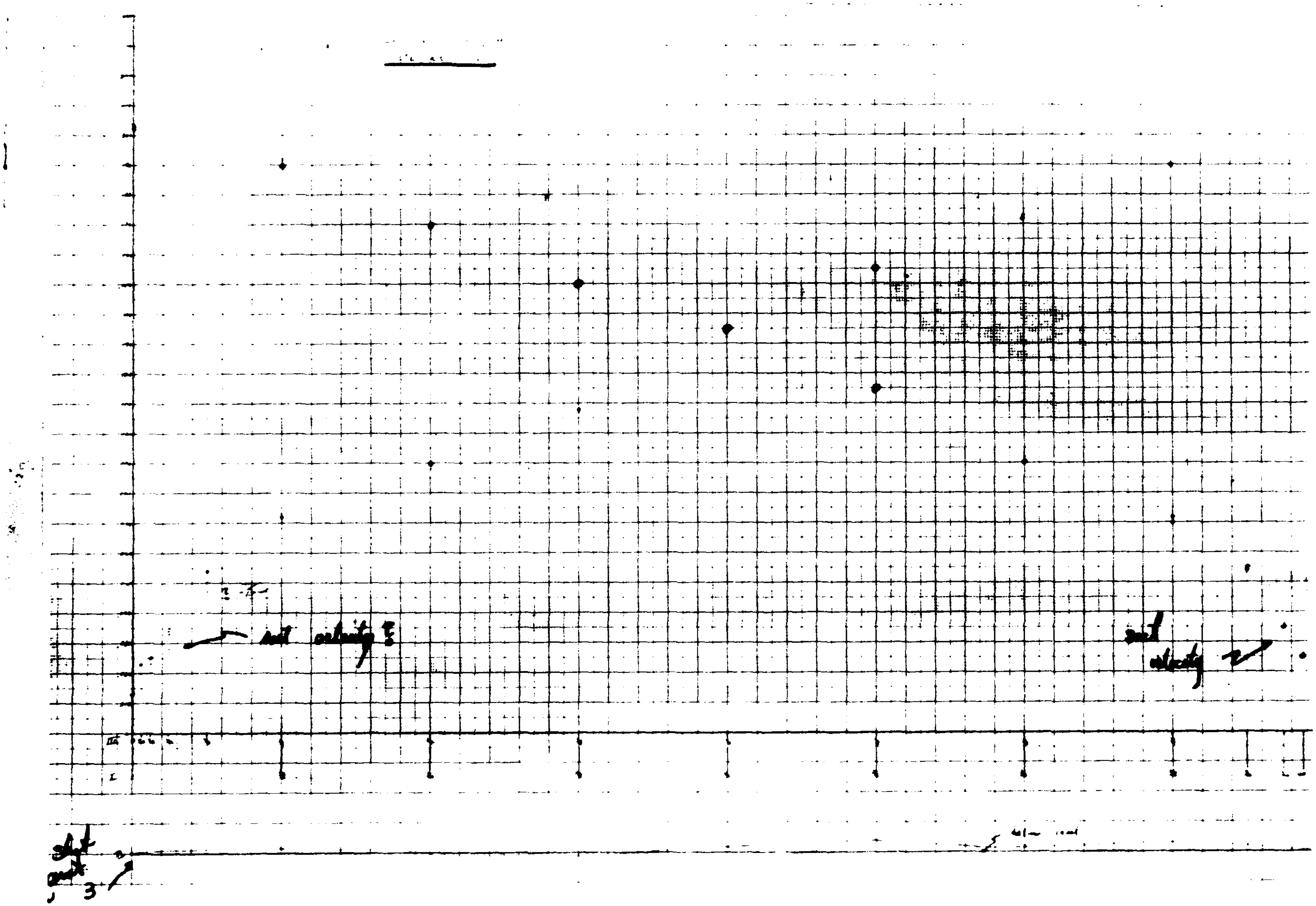


Figure 4

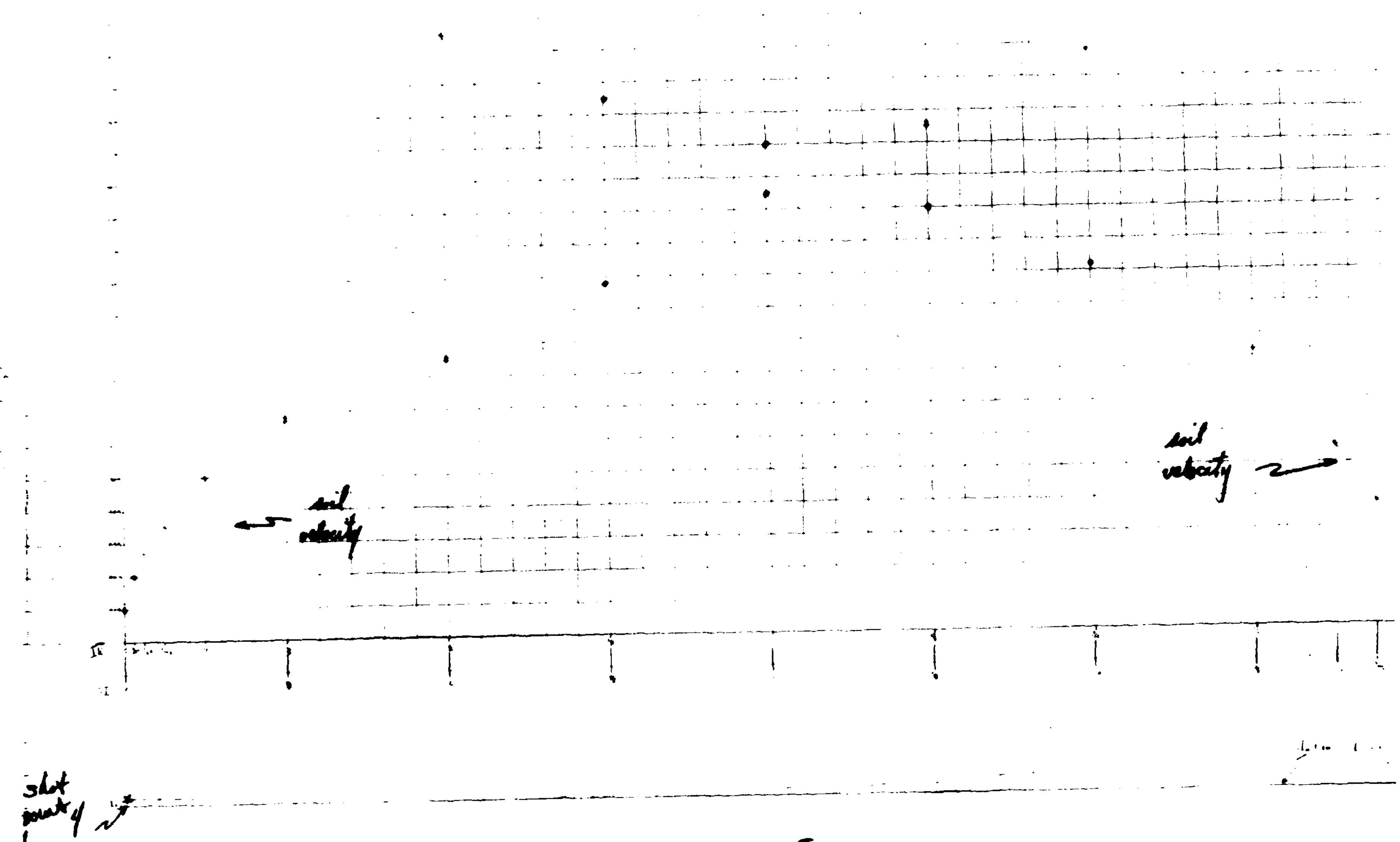


FIGURE 5

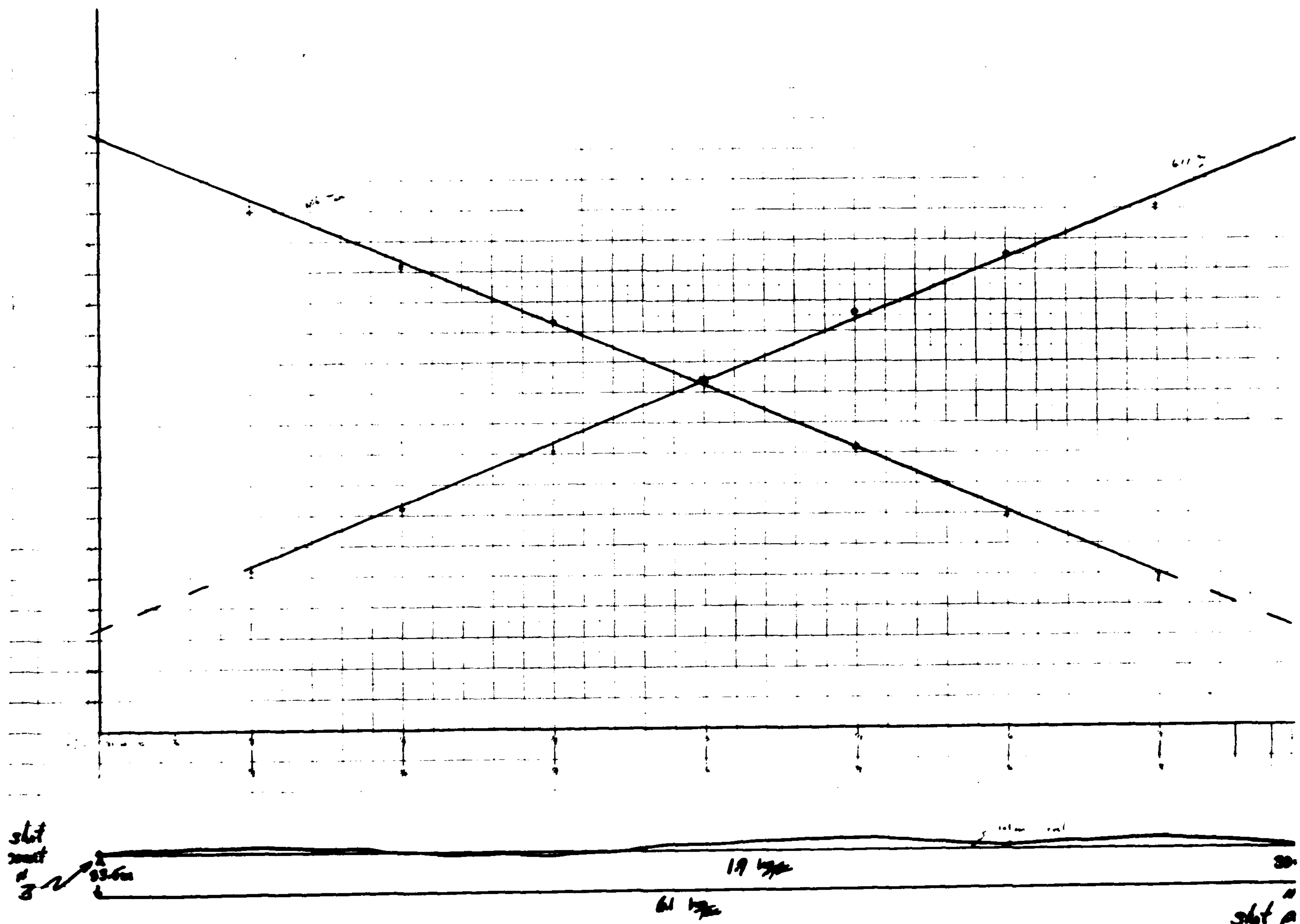


Figure 6

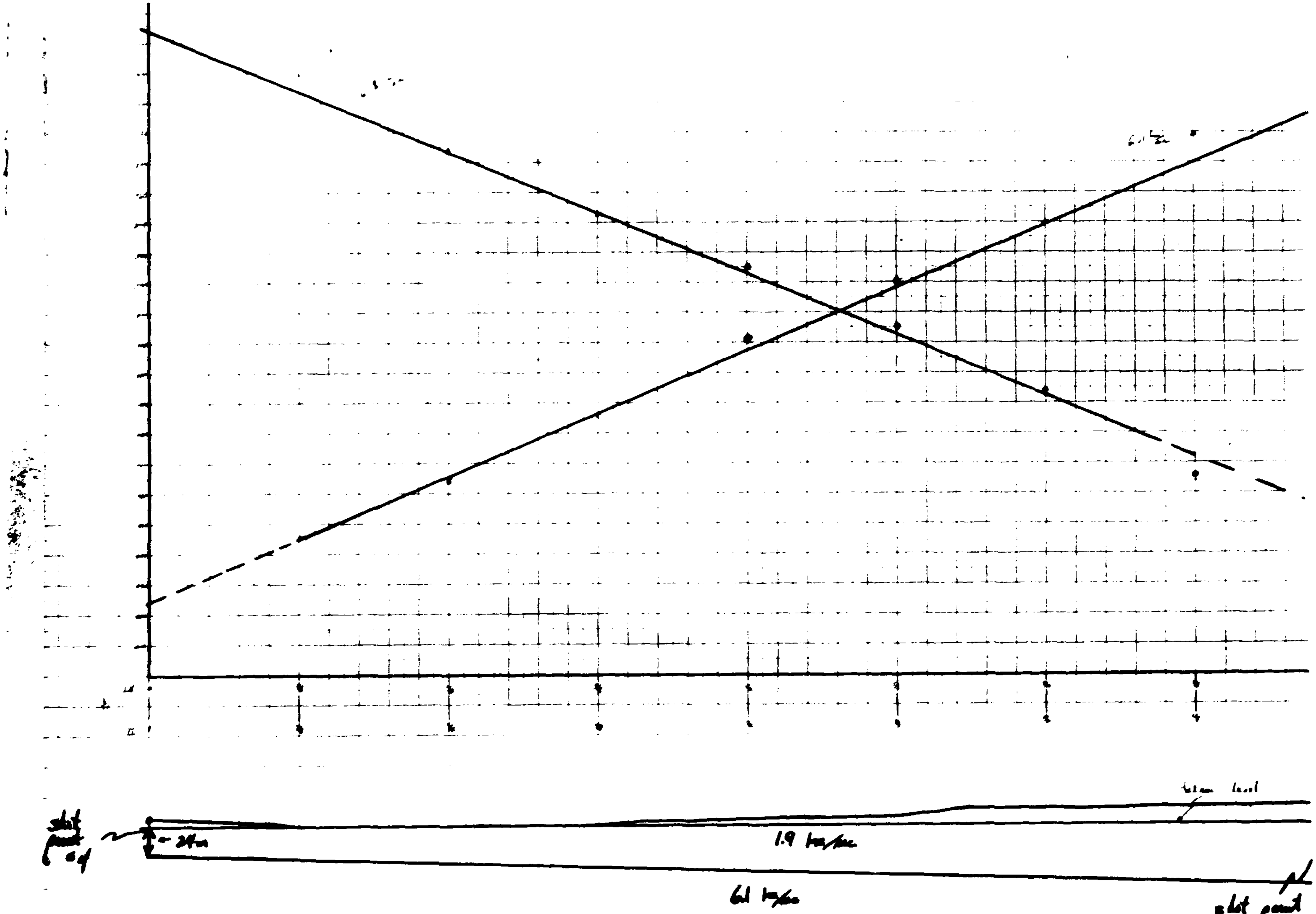


Figure 7

Figure 8. Propagation of the head wave. Within a certain distance range (a function of v, v_1, δ) all other propagation paths are slower.

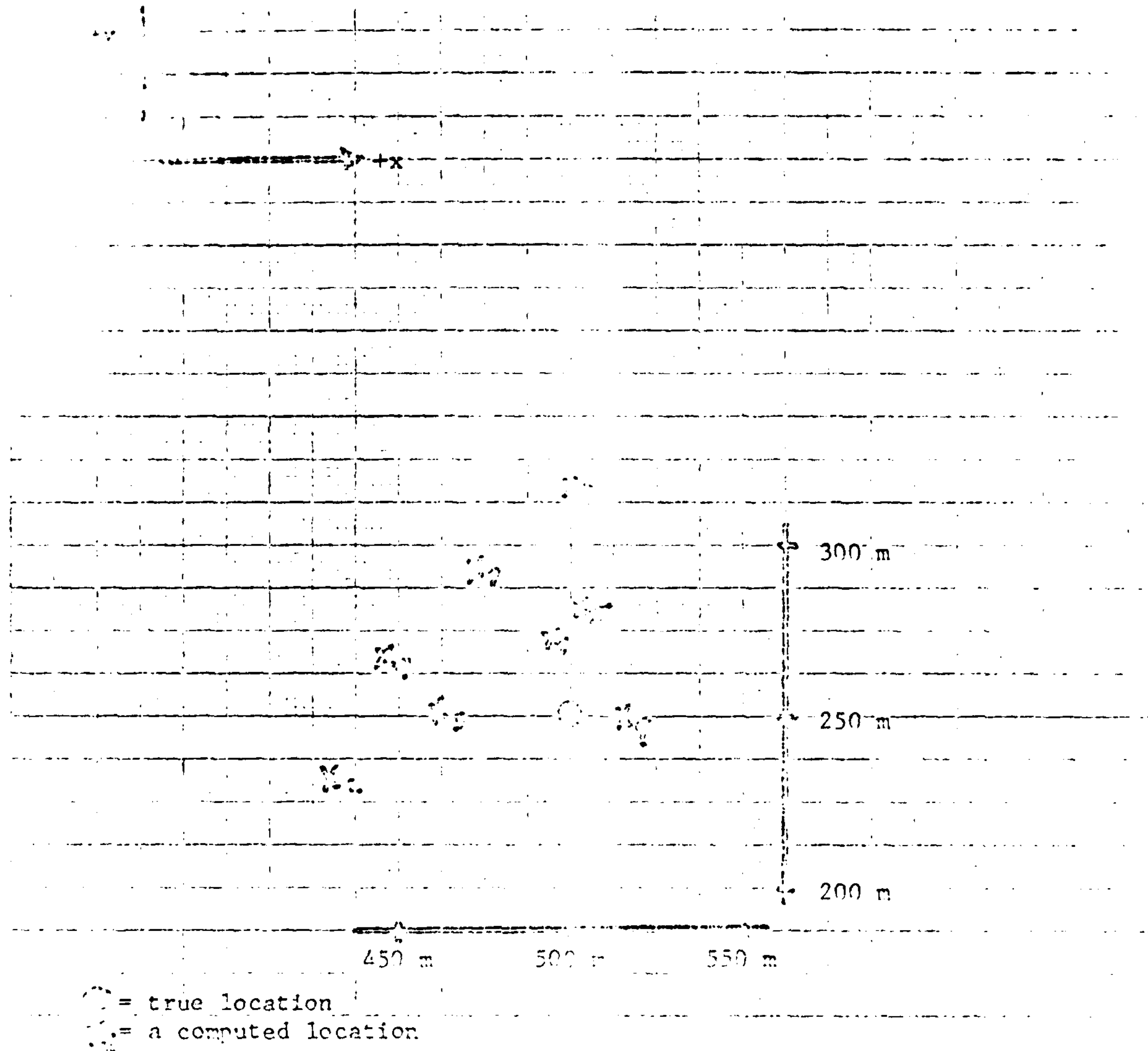


Figure 9a. Computed locations for the simulated mortar impact at 500 m. 250 m using a single effective velocity of 5.18 km/sec. No corrections for soil thickness or dip of interface were used. Note that the interface dips almost directly away from the array toward the impacts. Therefore correction for dip alone would probably correct the grossly incorrect ranges (y coordinates) and [illegible]ect the fairly accurate azimuths (x coordinates). Soil velocit[illegible]rections and elevation corrections would improve both x[illegible] values. Furthermore the use of a circular array of rad[illegible]0 m would insure that no ranges over approximately [illegible] m need ever be used in normal operation. Accuracy is improved at these closer ranges.

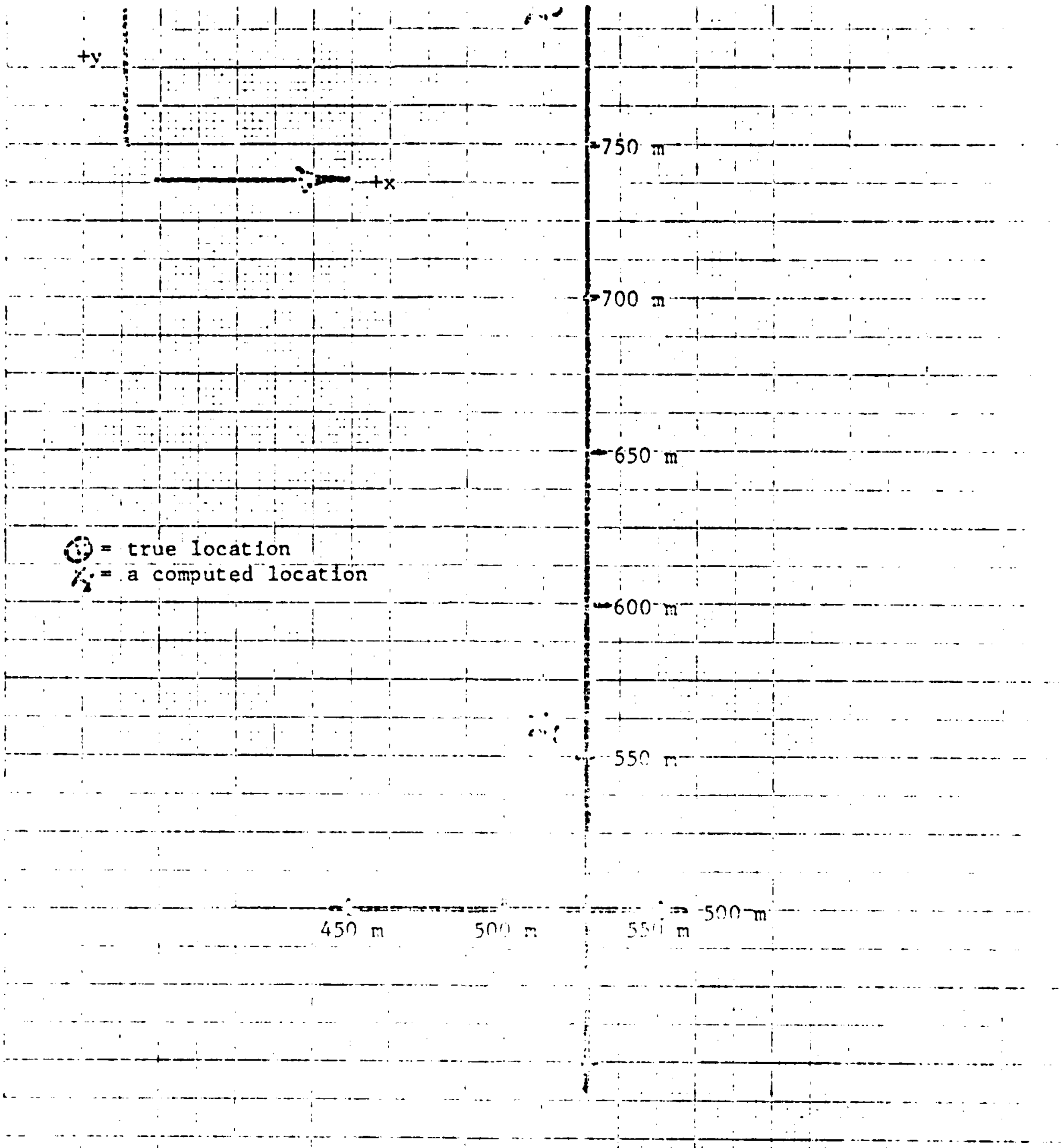


Figure 26. Computed locations for the simulated mortar impact at 500 m, 484.6 m using a single effective velocity of 5.18 km/sec. No corrections for soil thickness or dip of interface were used. Note that the interface dips almost directly away from the array toward the impacts. Therefore correction for dip alone would probably correct the grossly incorrect ranges (y coordinates) and effect the fairly accurate azimuths (x coordinates). [illegible] velocity corrections and elevation corrections would improve both x and y values. Furthermore the use of a circular array of radius 300 m would insure that no ranges over approximately 250 m need ever be used in normal operation. Accuracy is improved at these closer ranges.

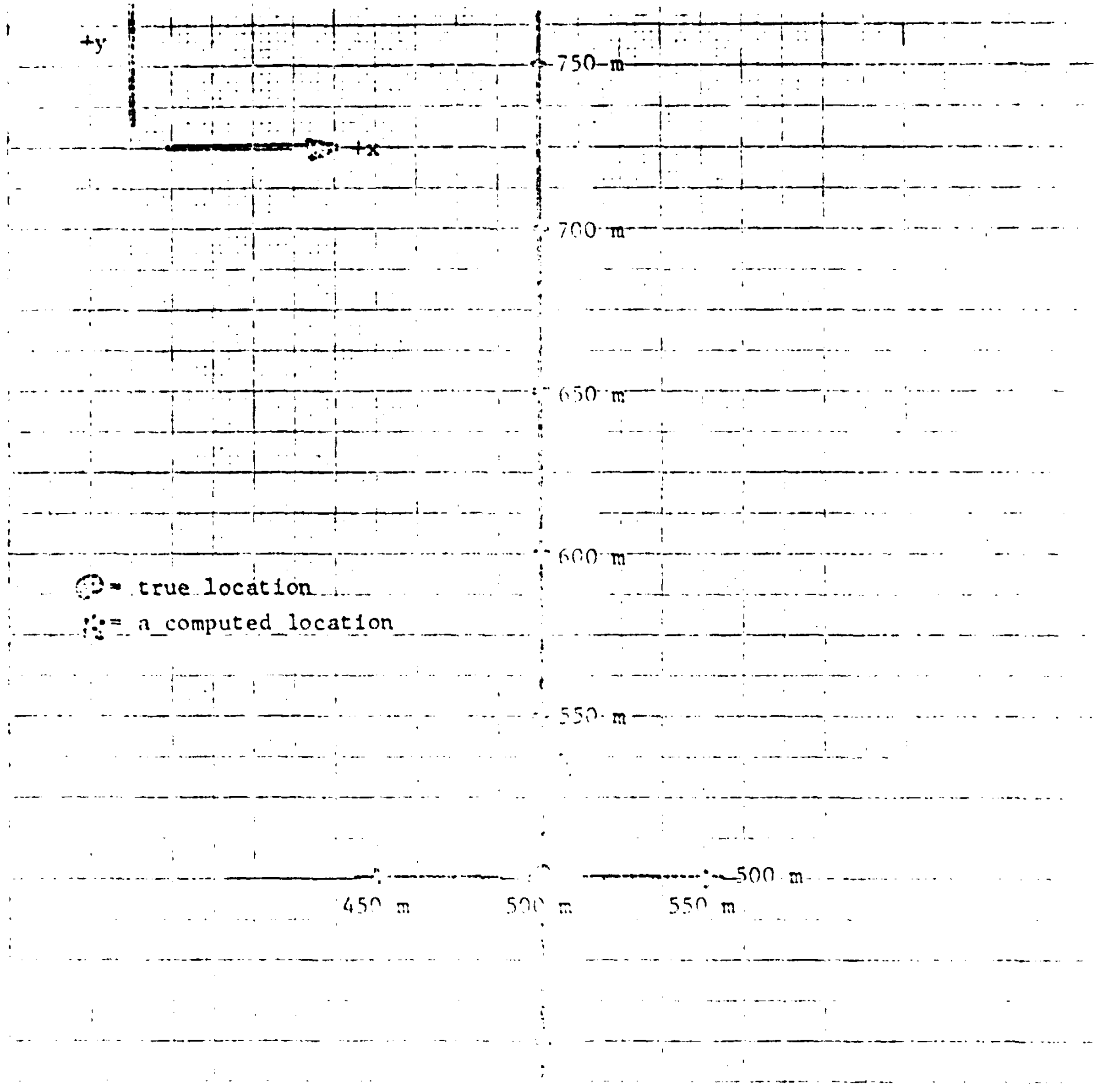


Figure 9c.—Computed locations for the simulated mortar impact at 500 m, 500 m using a single effective velocity of 5.18 km/sec. No corrections for soil thickness or dip of interface were used. Note that the interface dips almost directly away from the array toward the impacts. Therefore correction for dip alone would probably correct the grossly incorrect ranges (y coordinates) and effect the fairly accurate azimuths (x coordinates). Soil velocity corrections and elevation corrections would improve both x and y values. Furthermore the use of a circular array of radius 300 m would insure that no ranges over approximately 250 m need ever be used in normal operation. Accuracy is improved at these closer ranges.

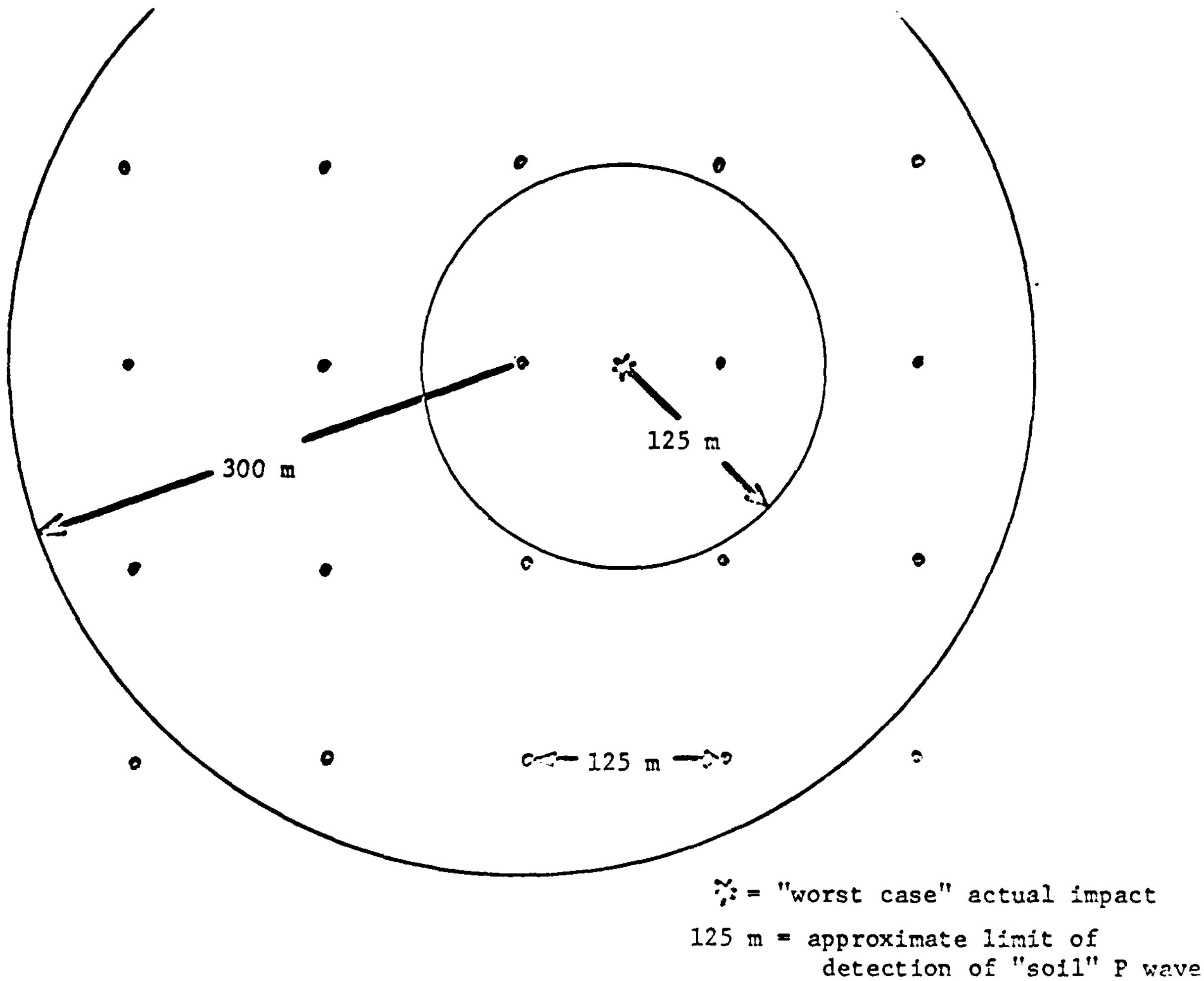
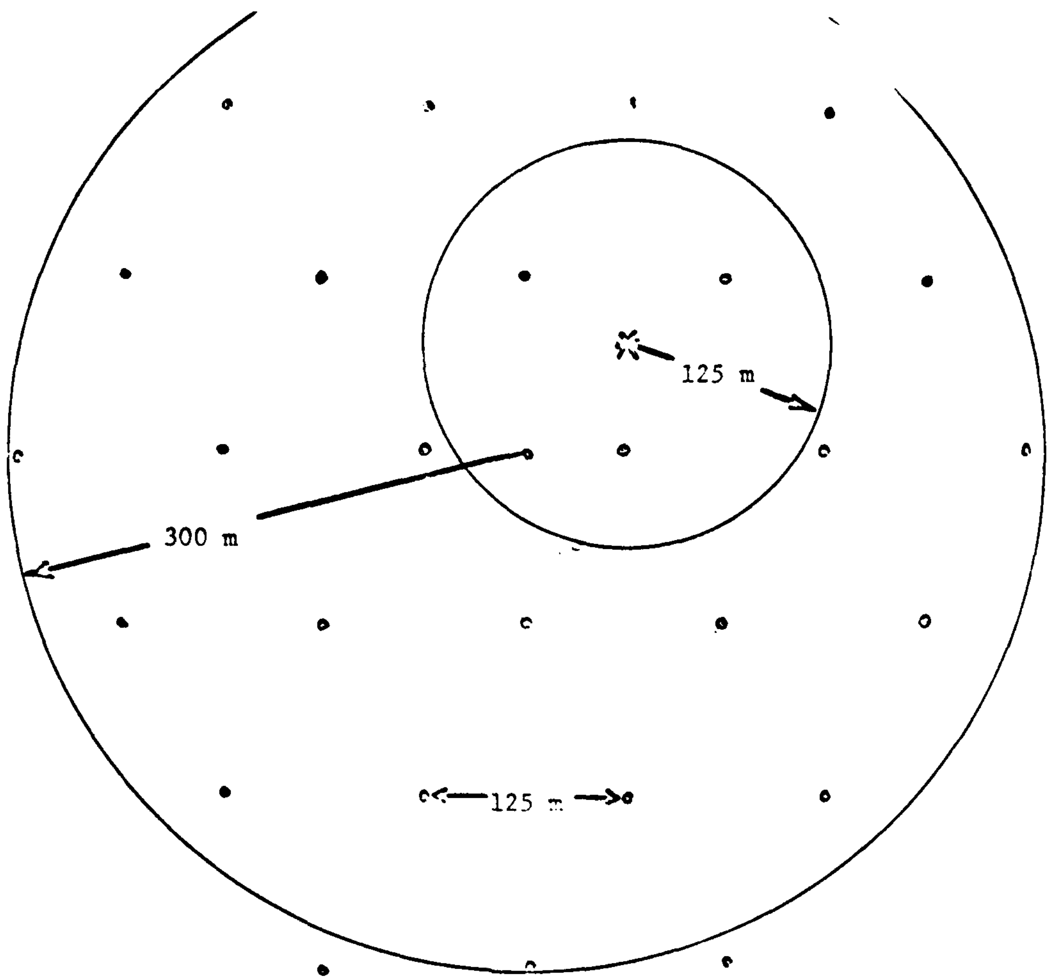


Figure 10. Hypothetical square array covering a target area of radius 300 meters. Array has 25 sensors. A "worst case" impact location is shown where only two sensors would record the "soil" P wave as a first arrival. Obviously the more sensors recording this P wave arrival from a randomly placed explosion the better the location would be. The array shown here would require the use of a computer.



= "worst case" actual impact

125 m = approximate limit of detection of "soil" P wave

Figure 11. Hypothetical hexagonal array covering a target area of radius 300 meters. Array has 30 sensors. A "worst case" impact location is shown where only three sensors would record the "soil" P wave as a first arrival. Obviously the more sensors recording this P wave arrival from a randomly placed explosion the better the location would be. The array shown here would require the use of a computer.

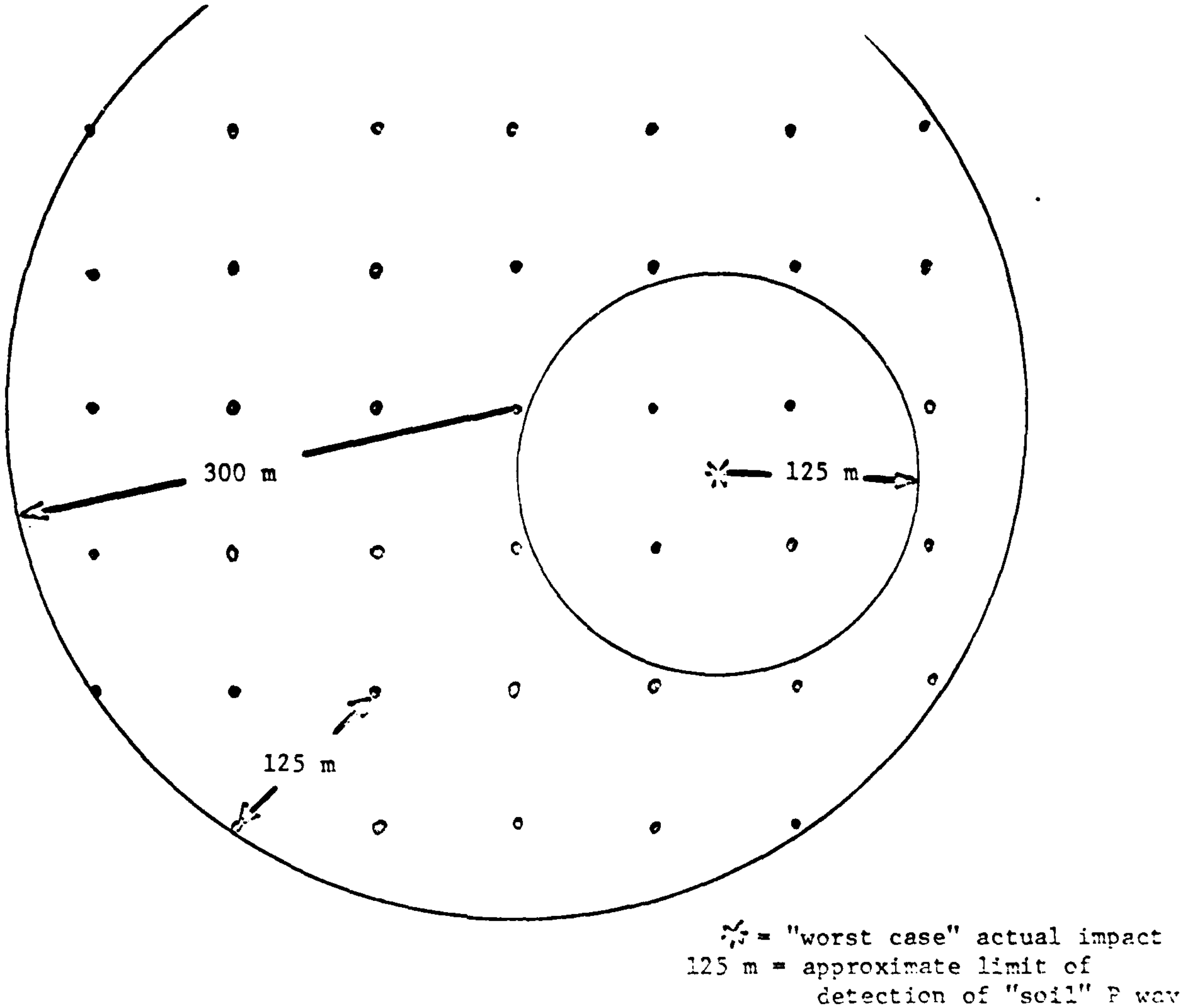


Figure 12. Hypothetical square array covering a target area of radius 300 meters. Array has 45 sensors. A "worst case" impact location is shown where only four sensors would record the "soil" P wave as a first arrival. Obviously the more sensors recording this P wave arrival from a randomly placed explosion the better the location would be. The array shown here would require the use of a computer.

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INFANTRY WEAPONS TEST METHODOLOGY STUDY. VOLUME V. INDIRECT FIR--ETC(U)
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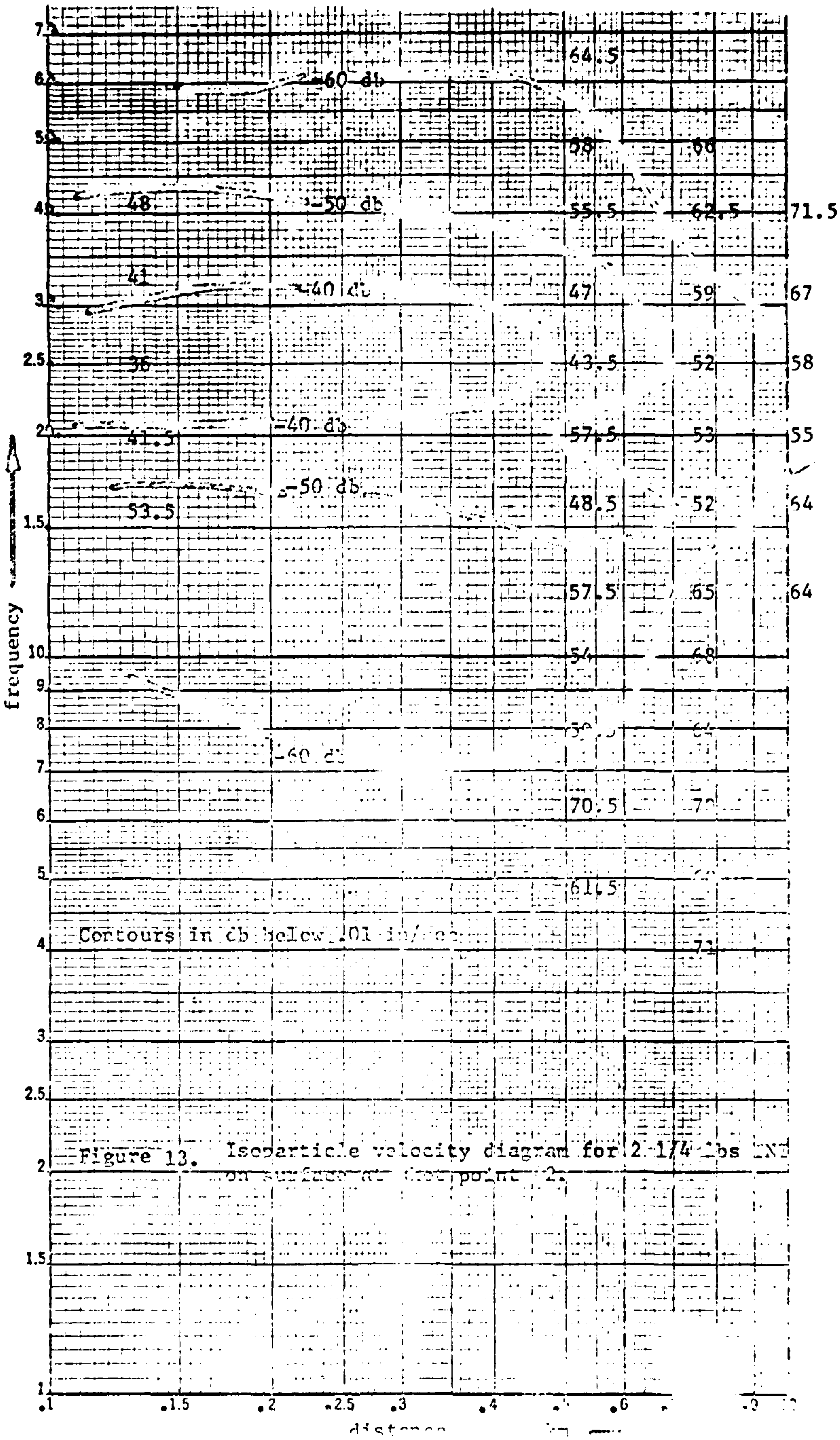


Figure 13. Isoparticle velocity diagram for 2 1/4 lbs TNT on surface at shot point 2.

Aug 1971

TAB C

TECHNICAL MEMORANDUM

Intersecting Line Method of Determining Point of Impact by Triangulation

Purpose:

This paper describes a simplified procedure for determining the point of impact using a triangulation method. The paragraphs below contain the mathematical proof and the procedure for employing the technique.

This technical memorandum has been prepared for future reference since the need for a triangulation method for measuring impact or burst location reoccures periodically.

Development:

The method of determining point of impact by triangulation described below consists of determining the equation of two straight lines and solving for the point of intersection.

Assuming the test facility is set up as shown below, two sighting devices are placed on an imaginary base line separated by a known distance (d).

Impact Area

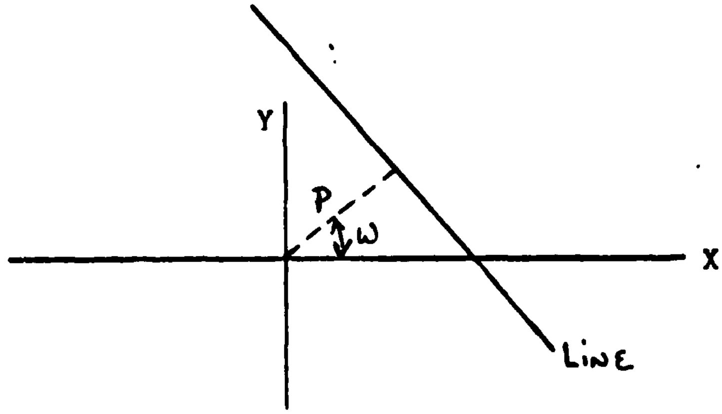
```
●-----------------------------------●
Position            d            Position
   1                                2
```

By superimposing a coordinate system over the two sighting points, the coordinates of the two positions become (0,0) and (d,0) as read from left to right.

The normal form of the equation of a straight line is

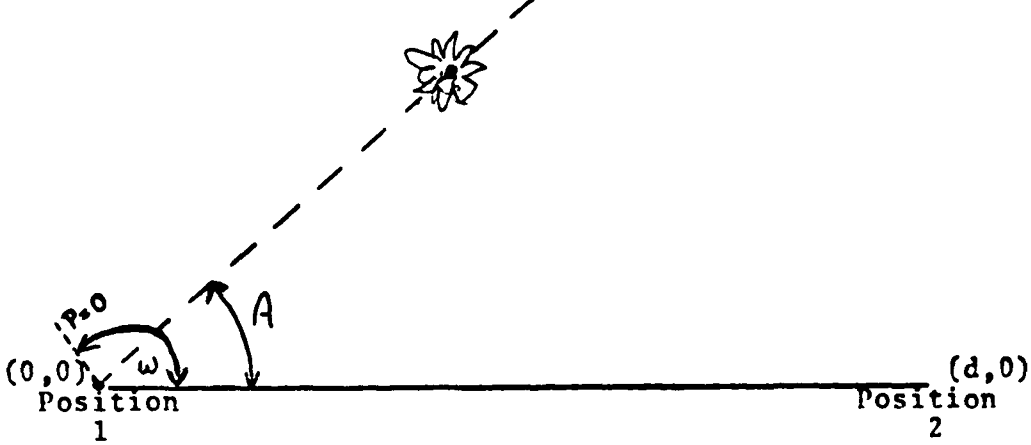
$$X \cos W + Y \sin W - P = 0$$

Where P is a positive number equal to the length of the normal drawn from the origin to the line. For example:



If the line passes through the origin, P = Ø.

Assume the left sighting position is at the origin of the coordinate system,

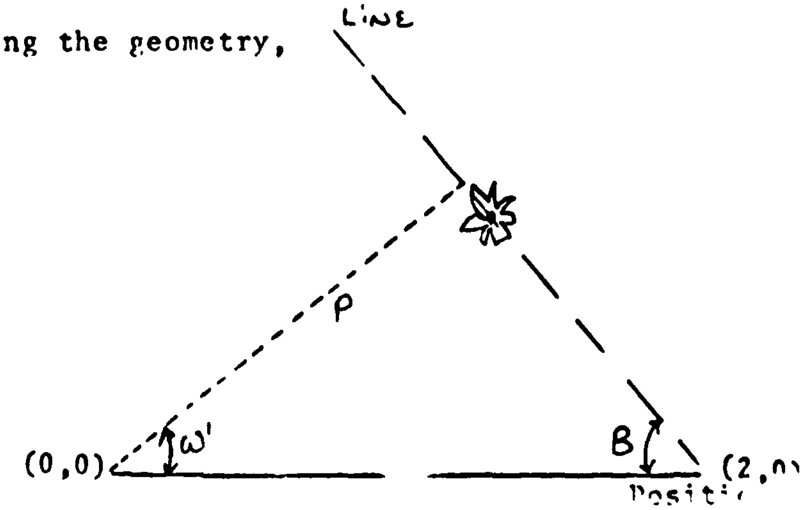


the equation for the line of sight becomes

$$X \operatorname{Cos} (A + 90) + Y \operatorname{Sin} (A + 90) = 0$$

where A is any angle from 0 - 90 degrees. If a similar equation can be determined for the line of sight from position 2 to the point of impact, the two equations can be solved simultaneously for the impact point.

Examining the geometry,



the normal P is shown passing through the origin. Since P is normal to the line of sight, a right angle is formed such that P can be expressed as a trignometric function:

$$\text{Sin } B = \frac{P}{d}$$

therefore, $\qquad P = d \text{ Sin } B$

Also the second angle ω^1 can be expressed as 90-B. The equation for the second line of sight equation is

$$L_2: \quad X \text{ Cos } (90-B) + Y \text{ Sin } (90-B) = d \text{ Sin } B$$

Hence, the two line of sight equations are

$$\text{Line 1:} \quad X \text{ Cos } (A + 90) + Y \text{ Sin } (A + 90) = 0$$
$$\text{Line 2:} \quad X \text{ Cos } (90-B) + Y \text{ Sin } (90-B) - d \text{ Sin } B = 0$$

Simplifying, we have

$$\text{Line 1:} \quad -X \text{ Sin } A + Y \text{ Cos } A = 0$$
$$\text{Line 2:} \quad X \text{ Sin } B + Y \text{ Cos } B - d \text{ Sin } B = 0$$

In solving the equations simultaneously we solve for X in equation 1

$$X = \frac{-Y \text{ Cos } A}{-\text{Sin } A} = \frac{Y \text{ Cos } A}{\text{Sin } A}$$

and substitute for X in equation 2

$$Y \frac{\text{Cos } A}{\text{Sin } A} \text{ Sin } B + Y \text{ Cos } B - d \text{ Sin } B = 0$$

If we multiply through by Sin A, we have

$$Y (\text{Cos } A \text{ Sin } B + \text{Sin } A \text{ Cos } B) - d \text{ Sin } A \text{ Sin } B = 0$$

Since

$$\text{Cos } A \text{ Sin } B + \text{Sin } A \text{ Cos } B = \text{Sin } (A + B)$$

we substitute and

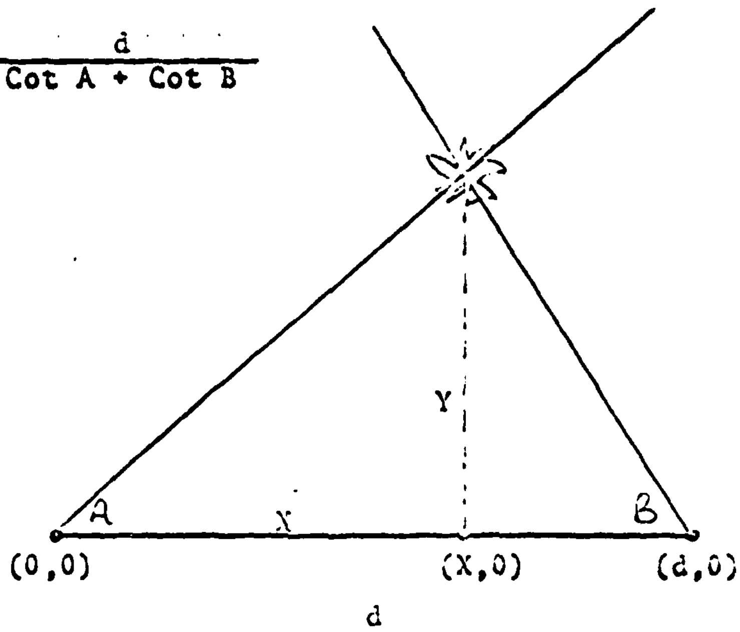
$$Y \text{ Sin } (A + B) - d \text{ Sin } A \text{ Sin } B = 0$$

Transposing, we get

$$Y = \frac{d \text{ Sin } A \text{ Sin } B}{\text{Sin } (A + B)}$$

Which equal to

$$Y = \frac{d}{\text{Cot A} + \text{Cot B}}$$



The value Y is shown above in the diagram. With Y known, the value of X can be determined.

$$\text{Cot A} = \frac{X}{Y}$$

$$X = Y \text{ Cot A}$$

Hence, the (x,y) coordinates can be determined using the triangulation method with the following two equations.

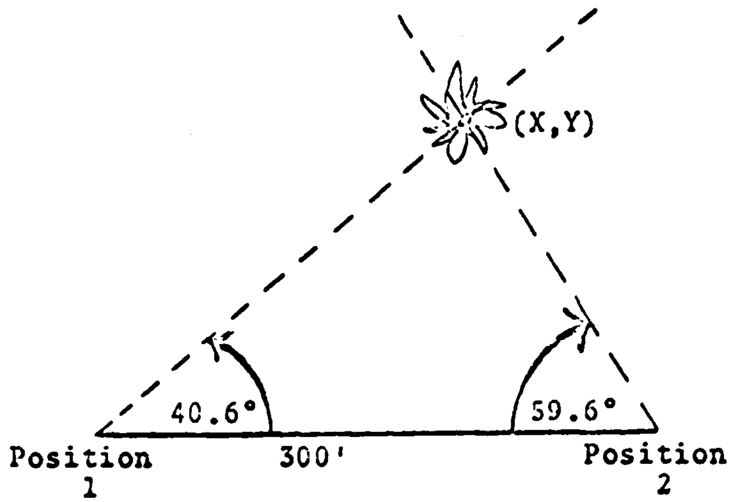
1. $Y = \dfrac{d}{\text{Cot A} + \text{Cot B}}$

2. $X = Y \text{ Cot A}$

All of the values in equation 1 are known or are read directly from the aiming device. Given the values, a simple two instruction FORTRAN program can be written to produce the coordinates of the impacting round. Note: If the theodolites or other sighting devices were linked directly to the computer so that angle is automatically fed in, results could be produced semi-automatically eliminating the possibility of errors in reading the scales, writing the data down and punching the information into the computer. [illegible]

Procedures for Using System

The following example will illustrate the technique described above:



$$Y = \frac{300}{\text{Cot } 40.6 + \text{Cot } 59.6} = \frac{300}{1.17 + .588} = 170.6'$$

$$X = 170.6 \text{ Cot } 40.6 = 1.17 = 199.6'$$

Two aiming devices are separated by 300 feet. The impact point is sighted and the angles from the base line are read. After placing these values into the two formulae, the value for the point of impact is determined.

2900-185-3

Report of Project MICHIGAN

PROPAGATION OF SOUND IN AIR

A Bibliography with Abstracts

JOHN W. WESCOTT
S. STEVEN KUSHNER

June 1965

Geophyics Laboratory
Institute of Science and Technology
THE UNIVERSITY OF MICHIGAN
Ann Arbor, Michigan

WADC TECHNICAL REPORT 57-353
PART II

SOUND PROPAGATION NEAR THE EARTH'S SURFACE AS INFLUENCED BY WEATHER CONDITIONS

M. D. Burkhard
H. B. Karplus
H. J. Sabine

Armour Research Foundation

DECEMBER 1960

Contract Nos. AF 33(616)-2470 and AF 33(616)-5091
Project No. 7210
Task No. 71709

BIOMEDICAL LABORATORY
AEROSPACE MEDICAL DIVISION
WRIGHT AIR DEVELOPMENT DIVISION
AIR RESEARCH AND DEVELOPMENT COMMAND
UNITED STATES AIR FORCE
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

[illegible] – May 1961 – [illegible]

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Report No. 312
Job No. 861

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CAPABILITIES AND LIMITATIONS INVESTIGATION OF LONG-RANGE PUBLIC ADDRESS EQUIPMENT

FINAL REPORT
PHASE 1
LITERATURE SEARCH AND PRELIMINARY THEORETICAL ANALYSIS
15 July 1954 to 31 May 1955

Signal Corps Contract No. DA-36-039 SC-64503
Department of the Army Project 3-99-12-022
Signal Corps Project 132B

U.S. Army, Signal Corps Engineering Laboratories
Fort Monmouth, N.J.

BOLT BERANEK AND NEWMAN INC.
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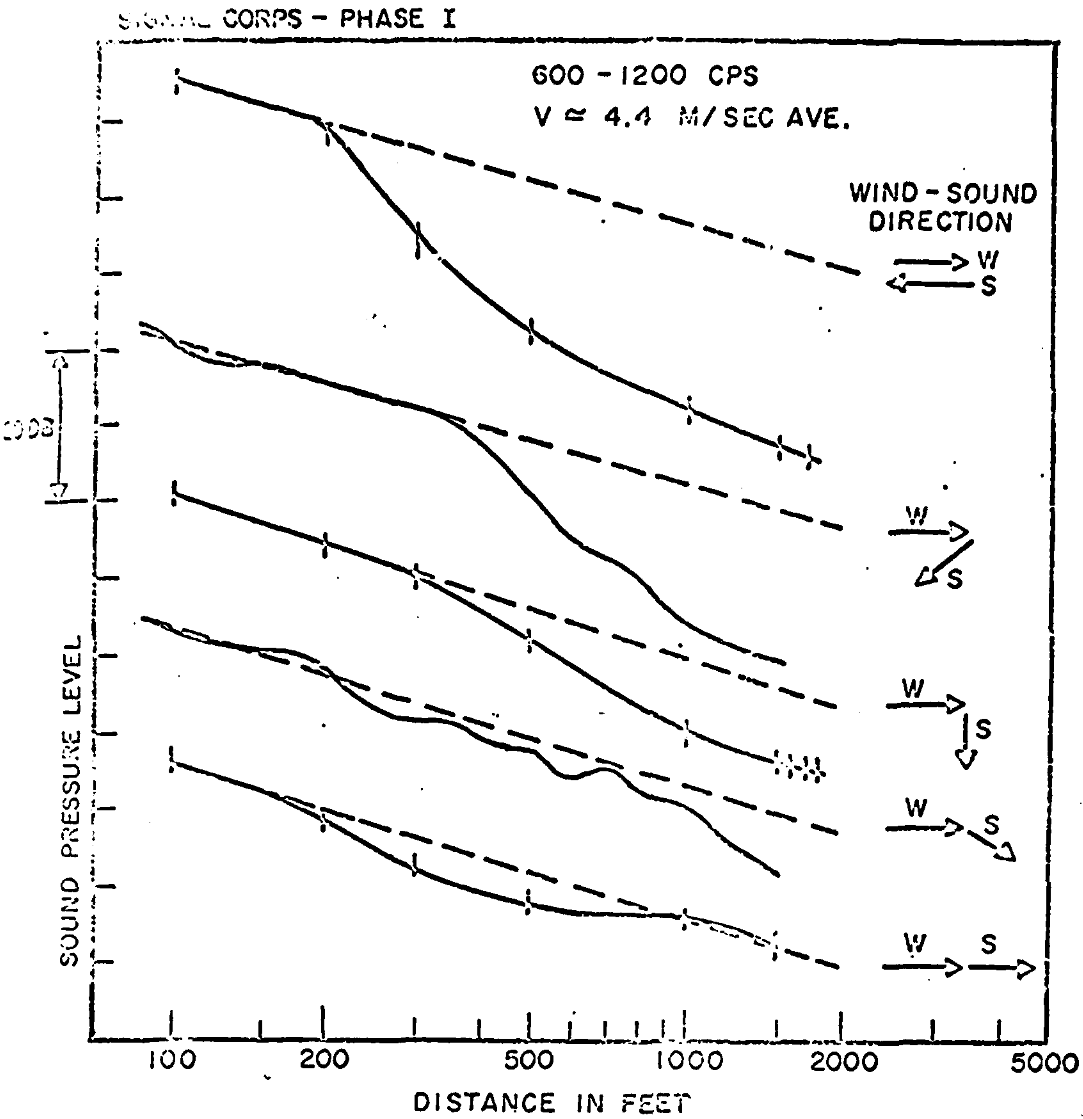

FIG. 1.7 VARIATION MEASURED OF SOUND PRESSURE LEVELS IN RELATION TO WIND VELOCITY.

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Table 9-4. Velocities in Sedimentary and Metamorphic Rocks

These are field and laboratory measurements as indicated. Faust [36] concludes that shale and sandstone show systematic correlation with depth and age. Faust's average velocity data based on 1 million feet of section in 500 Canadian and American well surveys are summarized in Figure 9-1. Average sand velocity exceeds average shale velocity by about 0.1 km/sec. Limestone velocity does not show as definite a correlation with depth and age but is very sensitive to the extent of crystallization. Because of porosity effects, the velocity in sedimentary rocks never reaches the intrinsic value of the components. Unlike the case of igneous rocks, it is virtually impossible to eliminate porosity effects by application of pressure [84].

Material	Velocities in km/sec V_p	V_s	Remarks*	Reference
Sandstone–Shale, U.S. and Canada				
Tertiary	2.1–3.5	..	*f*; *see Fig. 9-1*; Average	36
Cretaceous	2.4–3.9	..	sand velocity exceeds	..
Pennsylvanian	2.9–4.4	..	shale by about 0.1 km/sec. Velocity range for depth range 0.3–3.6 km.	.. ..
Ordovician	3.3–4.5	..	depth 0.3–2.1 km.	
Sandstone	1.4–4.3	..	..	13, 20, 21, 22, 23, 25, 27, 85
Sandstone conglomerate				
Australia	2.4	..	*f*	4
Limestone				
Soft	1.7–4.2	..	*f* and *l*	22, 32, 33, 31, 34, 35, 39, 87
Hard	2.8–6.4	..	*f* and *l*	14, 20, 21, 86, 35, 37, 41, 87
Solenhofen, Bavaria	5.97	2.88	*l*	7
Solenhofen, Bavaria	..	2.75	*l*	30
U.S. Midcontinent and Gulf Coast	3.4–6.1	..	*f*	29, 31
Argillaceous; Texas	6.02	3.03	*l*; 50 bars; ∥ to bedding	29
Argillaceous; Texas	5.71	3.04	⊥ to bedding	..
Dolomitic; Pennsylvania	5.97	..	*f*	14
Cement rock; Pennsylvania	7.07	.	*f*	14
Crystalline; Texas, New Mexico, Oklahoma	5.67–6.40	..	*f*; depth 1–3 km	36
Dense; Sochi, USSR	5.90–7.00	3.03–3.59	*f*	86
Salt, cornallite, sylvite	4.4–5.5	..	*f*	13, 24, 29, 35, 39
Caprock (salt, anhydrite, gypsum, limestone)	3.5–5.5	..	*f*	35, 39, 40, 41
Anhydrite				
U.S. midcontinent and Gulf Coast	4.1	..	*f*	29
Bashkir and Tatar, USSR	5.60	2.67–2.99	*f*	86
Gypsum				
U.S. and Germany	2.0–3.5	..	*f*	29, 41, 42
Chalk	2.1–4.2			
U.S., Germany and France	2.1–4.2	..	..	..
Austin, Tex.	2.58	1.07 SV	*f*; ⊥ bedding	34, 35, 44, 86
Austin, Tex.	3.05	1.13 SH	*f*; ∥ bedding	..
Slate				
Everett, Mass.	4.27	2.86	*l*	30
Shale and slate	2.3–4.7	..	*f*	4, 20, 22, 24, 32, 34, 45
Hornfels slate	3.5–4.4	..	*f*	4
Taconite				
Minnesota	4.3–6.3	..	*f*	28

TABLE 9-4. *Continued*

Material	Velocities in km/sec V_P	V_S	Remarks*	Reference
Magnetite ore				
Ukraine [USSR]	5.50	..	f; $V_P/V_S \sim 1.67–1.72$	86
Dolomite	3.5–6.9	..	f and l	28, 38, 6
Marble				
Japan, Korea, Italy	3.75–6.94	2.02–3.86	l; range 46 samples	17
	5.78	3.22	average 46 samples	..
Danby, Vt.	5.87	2.82	l; 70 bars	..
Quartzite				
West Virginia	6.1	..	f	15
Cheshire	6.0	..	l; 90 bars	7
Chlorite schist				
Framingham, Mass.	4.89	3.27	l	30
Amphibolite schist				
Ukraine, USSR	4.2	2.5	f	86
Gneiss				
Wisconsin	6.71	..	f	28
New Hampshire	3.54–4.60	..	f	85
Ukraine, USSR	3.50	..	f; $V_P/V_S \sim 1.75–1.94$	86
Spain	5.15–7.50	..	f	39
New York, Massachusetts, Quebec	..	3.43–3.[illegible]	l; 4000 bars, 5 samples	74
Wet clay				
USSR (6 locations)	1.50–1.65		f; $V_P/V_S \sim 4.5–13.7$	86
Clay				
Baltic Shield (Leningrad)	1.20–2.50	..	f, V_P/V_S 2.08–8.5	86
Impermeable argillaceous clay	2.00	.50	f	..
Sand				
Baltic Shield and Caucasus	.60–1.85	..	f, $V_P/V_S \sim 3.0–3.5$	86
Soil	.11–.20	..	f, $V_P/V_S \sim 1.7–2.0$	86
Volcanic tuff				
New Zealand	2.16	[illegible]	f	88

* f = field determination; l = laboratory determination

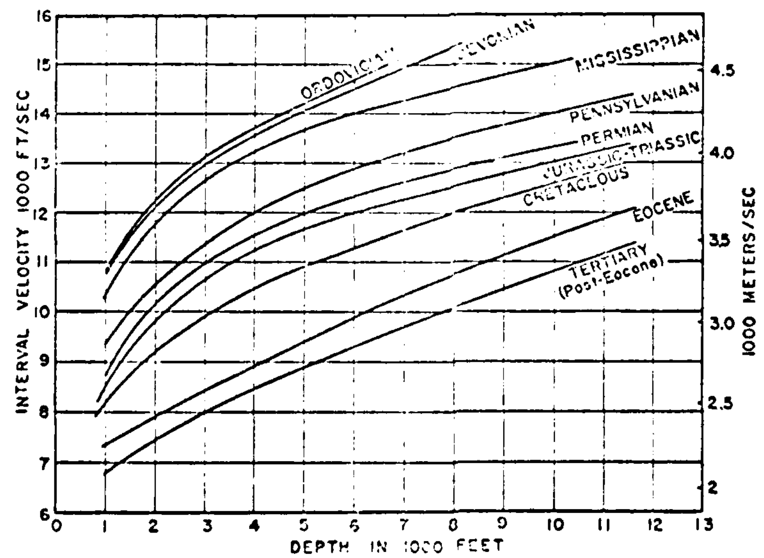


Figure 9-1. Compressional velocities from [illegible] holes in sandstone-shale sections for depth intervals of 1000 feet [*after* Faust, 36]

TABLE 9-5. WAVE VELOCITIES IN UNCONSOLIDATED SEDIMENTS

Water saturation is a significant factor influencing compressional velocity but having no effect on shear velocity. Nafe and Drake [78] have developed theoretical-empirical velocity depth curves (Fig. 9-2) which fit a wide variety of laboratory and field measurements on submarine sediments.

Material	Velocity in km/sec V_p	V_s	Remarks*	Ref.
Alluvium	.5 –2.0	..	*f*; near surface	3, 39, 45
	3.0 –3.5	..	*f*; depth 2000 meters	..
Clay	1.1 –2.5	..	*f*	4, 26, 34, 46, 47
Diluvium	.7 –1.8	..	*f*	23, 34, 39
Embankments and fill	.4	..	*f*	39
Loam	.8 –1.8	..	*f*	4, 21
Loess	.3 – .6	..	..	19, 46
Sand				
loose	.2 –2.0	..	*f*	3, 10, 19, 23, 29, 32, 34, 39, 41
loose	1.0	.4	*f*; above water table	43
loose	1.8	.5	*f*; below water table	43
calcareous	.8	..	*f*	42
wet	.75–1.5	..	*f*	41, 68
Weathered layer	.3 – .9	..	*f*	29
Glacial				
till	.43–1.04	..	*f*; unsaturated	28
till	1.73	..	*f*; saturated	28
sand and gravel	.38– .50	..	*f*; unsaturated	28
sand and gravel	1.67	..	*f*; saturated	28
River, Bay	1.1 –1.8	..	..	48, 49
Suboceanic	over 1.6	over .6	*f* and *l*; see Figure 2	78
Shallow water fine-grained; off San Diego, Calif.	1.46–1.68	..	in situ ultrasonic measurement sea water	50

* *f* = field determination; *l* = laboratory determination

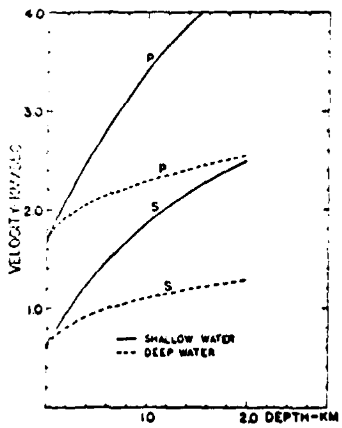


Figure 9-2. Wave velocities in submarine sediments [*after* Nafe and Drake, 78]

APPENDIX V

Signal Conditioning Specifications

1. Introduction. An instrumentation system capable of scoring impacts within the area depicted by Figure 15, Volume V using either seismic or acoustic sensors could be fabricated. In either case, all signal conditioning should be located with the ADPE in the computer van. Coaxial cable, RG-58C/U, should be used to link each sensor to an appropriate conditioner.

2. Seismic Signal Conditioner. This conditioner is used in conjunction with a seismometer such as the Geo Space HS-1, 7.5Hz miniature refraction detector on-hand. It is composed af an amplifier, action low-pass filter, level detector and one-shot (see Figure 5-1).

Initially, input signals are amplified by the variable gain amplifier (voltage gain variable between -1 and -21). Next the signal is passed through the active low-pass filter having a voltage gain of 5 and cutoff frequency of 1KHz.

Any signal reaching the level detector with amplitude exceeding the reference voltage produces an output at the comparitor. The common voltage reference, which is variable, is provided to override noise, zero offset and drift voltages from the amplifier and filter.

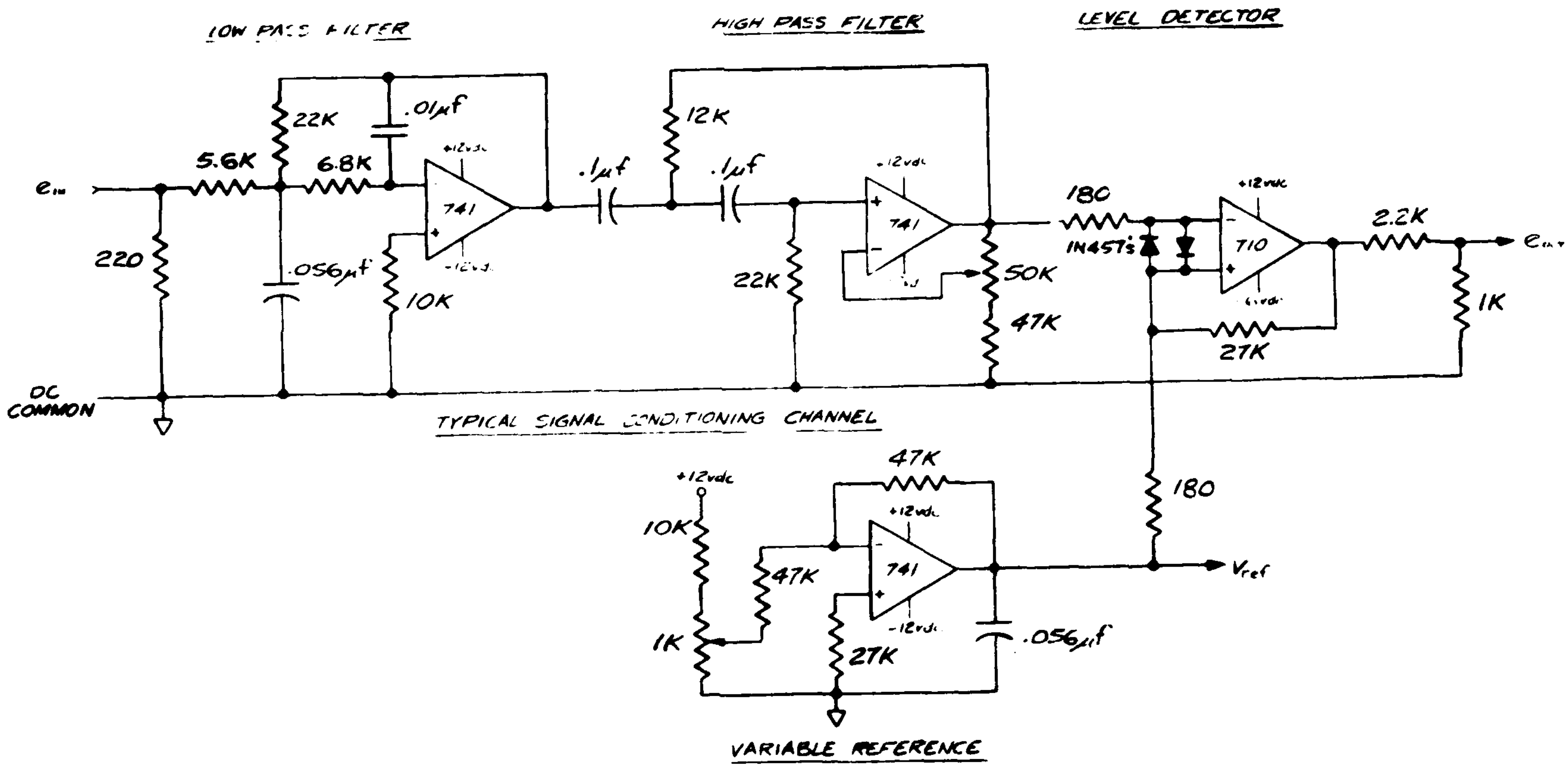
The output from the level detector is conditioned and used as the input to the one-shot. The resulting output pulse duration of approximately 1 second. This 1 second pulse is attenuated and fed into an appropriate California Avionics I-550 Microphone Signal Conditioner channel.

3. Acoustic Signal Conditioner. This conditioner is used with an acoustic sensor such as the Electro-Voice 649B microphone which is on-hand. It includes two double pole action filters and a level director (see Figure 5-2). First is a low-pass filter having a gain of -4 in the pass band; its cutoff frequency is 500Hz. It should be noted that the input impedance of approximately 200 ohms has been provided to match the output impedance of the E-V649B microphone. This load on the microphone attenuates its open circuit output by a factor of 2.

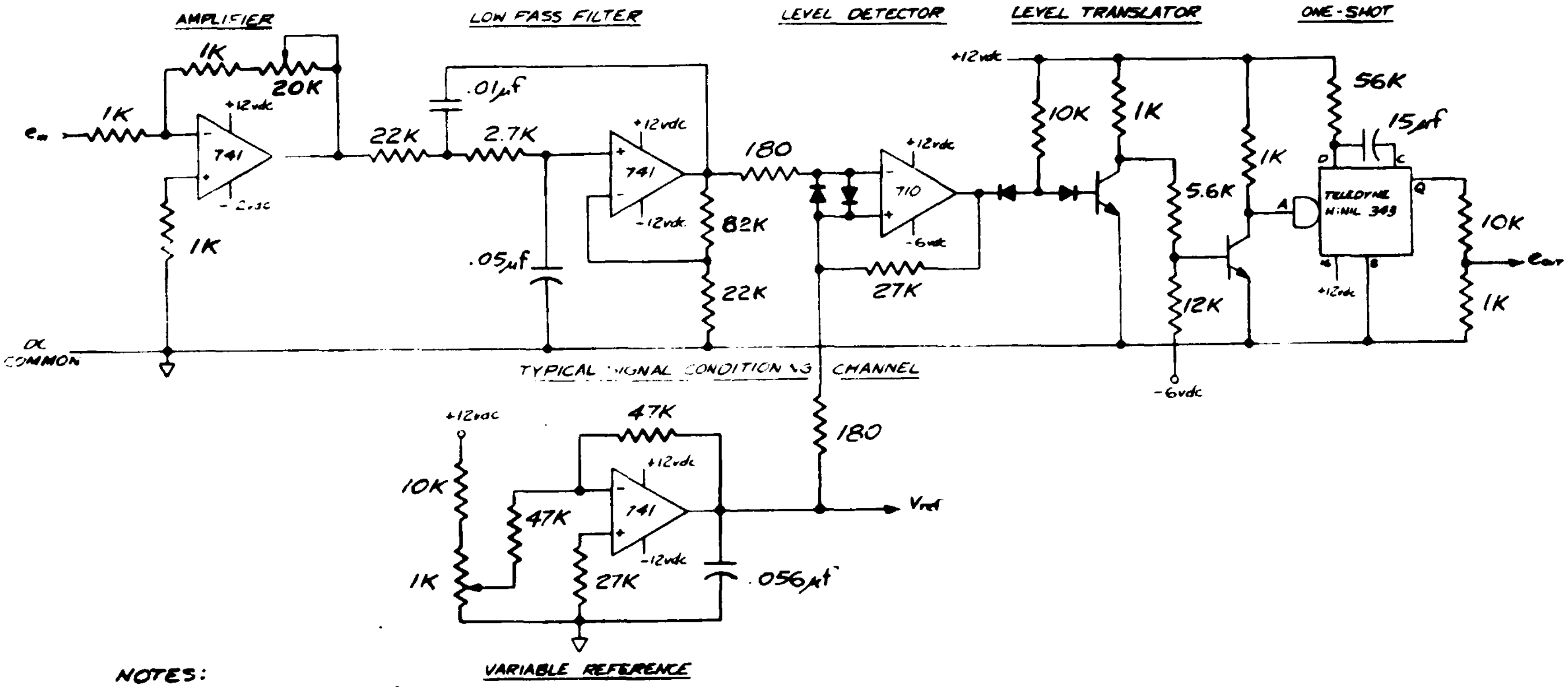
The low-pass filter is followed by a vatiable gain high-pass filter (voltage gain variable between 1 and 2); its cutoff frequency is 100Hz. The combination of these filters gives a band pass of 400Hz (from 100Hz to 500Hz).

Any signal passing through the filter with amplitude exceeding the reference voltage produces an output at the comparitor. The common voltage reference is provided to override noise; zero offset and drift voltages from the filters.

The level detector output is fed into a California Avionics I-550 microphone signal conditioning channel.



ACOUSTIC SIGNAL CONDITIONER
FIGURE 5-2



NOTES:
1) DIODES ARE IN457's.
2) TRANSISTORS ARE 2N2222's.

SEISMIC SIGNAL CONDITIONER
FIGURE 5-1

DATE
FILMED

8